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AMERICAN ACADEMY OF ARTS AND SCIENCES.

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PROCEEDINGS

OF THE

AMERICAN ACADEMY

OF

ARTS AND SCIENCES.

VOL. XXIX.

PAPERS READ BEFORE THE ACADEMY.

I.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON CERTAIN SUBSTITUTED CROTONOLACTONES AND MUCOBROMIC ACID.*

By Henry B. Hill and Robert W. Cornelison.

Presented April 12, 1893.

Several years ago a dichlorpyromucic acid was described by Hill and L. L. Jackson,† which differed from all the substituted pyromucic acids then known, in that it was readily decomposed by concentrated hydrochloric acid at 100° at ordinary pressures. Carbonic dioxide was evolved and a neutral body was formed which melted at 52–53°, and contained a percentage of chlorine which corresponded to the formula $C_4H_3ClO_2$. A body of similar properties melting at 77° had previously been found in small quantity by Hill and Sanger ‡ among the products formed from pyromucic tetrabromide by the action of an alcoholic solution of sodic hydrate. A complete analysis of this body had shown that its formula was $C_4H_3BrO_2$, but a lack of material rendered a detailed study of it impossible. While the chlorine derivative was more accessible, it was not more carefully studied by Hill and L. L. Jackson since it was discovered only at the close of their investigation of the chlorpyromucic acids. They were also but partially successful in determining the constitution of the χ-dichlorpyromucic acid from which it was so easily formed. They showed that one chlorine atom of this acid was in the δ position, but could bring forward no definite facts to prove whether it was a $\beta\delta$-dichlorpyromucic acid stereometrically isomeric with the common form, or whether it was the third possible structural isomer, the $\gamma\delta$-dichlorpyromucic acid. In the former case its ready decomposition by aqueous hydrochloric acid might be due to its peculiar configuration, in the latter case this reaction might be conditioned by the simultaneous presence of halogens in the γ and δ positions. If the instability of the acid were due to the positions occupied by the halogen atoms, it seemed probable that the tri-substituted pyromucic acids which also contain halogen in the γ and δ places would show the same behavior. Although Hill and Sanger had observed no such decomposition in studying tribrompyromucic acid, and Hill and L. L. Jackson noticed no such reaction with the trichlorpyromucic acid, in neither case had direct experiments in this direction been made, and it was quite possible that the decomposition in question had been overlooked. It was soon found, on trial, that tribrompyromucic acid was decomposed in analogous fashion, but that the reaction was effected with much more difficulty, so that a temperature materially above 100° was necessary in order to bring it about. When heated to boiling with concentrated hydrobromic acid, carbonic dioxide was evolved and a body melting at 90–91° was formed, which showed a close resemblance to the monohalogenized bodies already known, and which had the similar formula $C_4H_2Br_2O_2$. From trichlorpyromucic acid the analogous body $C_4H_2Cl_2O_2$, melting at 50–51°, could be made without difficulty. In studying the behavior of other substituted pyromucic acids under the same conditions, it was found that the $\beta\delta$-dibrompyromucic acid could also be made to undergo the same decomposition, although but a comparatively small yield of a body $C_4H_3BrO_2$ melting at 58° could thus be obtained. This mode of decomposition was, therefore, not confined to those acids which contained halogen at the same time in the γ and δ positions. By following an entirely different method it was found that the $\beta\delta$-dibrompyromucic acid could be converted into an isomeric body, $C_4H_3BrO_2$, which melted at 77°, and was identical with that which had already been discovered by Hill and Sanger. The $\beta\delta$-dibrompyromucic acid was treated with bromine in aqueous solution, and the brommaleylbromide, $C_4HBr_3O_2$, which, according to the observations of Hill and Sanger,* is thus formed, when carefully reduced by zinc dust and glacial acetic acid, yielded the body melting at 77°. The mucobromylbromide $C_4HBr_3O_2$ described by Hill and O. R. Jackson † was so simply related, as far as its empirical formula was concerned, to the body $C_4H_2Br_2O_2$ formed from tribrompyromucic acid, that it seemed possible to establish experimentally a direct connection between the two. It was found that mucobromylbromide could readily be reduced by a variety of reducing agents, and that under certain conditions a nearly quantitative yield of the body $C_4H_2Br_2O_2$ melting at 90–91° could be obtained from it. Moreover, this reaction could be reversed and mucobromylbromide obtained by the action of bromine upon this reduction product. In the same way, by the reduction of mucochlorylbromide the body $C_4H_2Cl_2O_2$ melting at 50–51°, which had been made from trichlorpyromucic acid, could readily be obtained in any desired quantity.

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* A part of the work described in the following paper was presented in the form of a thesis to the Faculty of Arts and Sciences of Harvard University in May, 1893, by Robert W. Cornelison, then candidate for the degree of Doctor of Philosophy.

† These Proceedings, XXIV. 348.

‡ Ibid., XXI. 158.

Since the several bodies already mentioned were evidently perfectly similar in their structure, we chose for more detailed study the body $C_4H_2Br_2O_2$, which was the most readily accessible. The melting point of this substance, 90–91°, was not far removed from that assigned (88°) by Toennies ‡ to a body of like formula, which he obtained by the oxidation of $\beta\gamma$-dibrompyromucic acid with bromine water, and it was not difficult to suppose the two bodies identical. Toennies published no analyses whatsoever of his product, and Hill and Sanger § were unable to obtain the substance in larger quantities; but according to their observations a preparation which gave the proper percentage of bromine melted at 89–90°. A careful comparison of the substance prepared according to Toennies with that obtained by the decomposition of tribrompyromucic acid, or by the reduction of mucobromylbromide, showed the two bodies to be identical in every respect. The formation of dibrommaleic acid by the prolonged action of nitric acid upon this body sufficiently established the relative position of the two bromine atoms and left for its constitution the choice between the following formulæ: —

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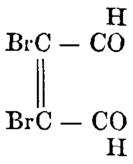
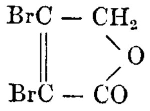
* These Proceedings, XXI. 166.

† Ibid., XVI. 174.

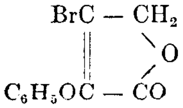
‡ Berichte d. deutsch. chem. Gesellsch., XII. 1202.

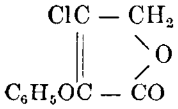
§ These Proceedings, XXI. 172.



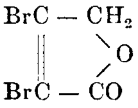


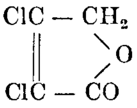
Toennies found that his product could be converted into mucobromic acid by oxidation with chromic acid, and therefore considered it to be the double aldehyde of dibromfumaric acid. We found, on the other hand, that the body showed none of the ordinary characters of an aldehyde. On warming with chromic acid it was slowly oxidized, but mucobromic acid was not formed in quantity sufficient to enable us to identify it with precision. On long boiling with bromine and water mucobromic acid was formed. From concentrated nitric acid it could be recrystallized unchanged, and only after continued boiling was it oxidized to mucobromic and dibrommaleic acids. It did not combine with acid sodic sulphite, and did not react with hydroxylamine. Aniline in alcoholic solution removed one atom of bromine and gave a phenylamido derivative of the form $C_4H_2(C_6H_5NH)BrO_2$, and phenylhydrazine also removed bromine. Aqueous alkalies dissolved it with the formation of a deep yellow solution, but decomposition soon ensued with the elimination of hydrobromic acid. The whole behavior of the body was in direct opposition to the assumption that it was a double aldehyde, and the unsymmetrical structure was further established by the existence of two isomeric bodies of the same general constitution which contained a single bromine atom. The conclusion was inevitable that the body was a dibromcrotonolactone. The rigorous proof of its lactone structure, through its conversion into a salt of the corresponding oxy-acid was rendered difficult by the presence of the halogen since the halogen itself was rapidly removed in alkaline solution. By adding a decinormal solution of potassic hydrate to a cold dilute solution of the substance it is true that it was easy to prove that very nearly two molecules of potassic hydrate were neutralized in the reaction, while but one molecule of potassic bromide was formed, but it was impossible to isolate definite products of the decomposition. On reducing the body with zinc and dilute sulphuric acid the bromine was completely removed, and on distillation a feebly acid solution was obtained, which on titration with decinormal potassic hydrate proved to contain a lactone. By the usual methods an amorphous barium salt was obtained, which when thoroughly dried had the percentage composition required by a baric oxycrotonate. The isolation of the crotonolactone itself proved to be a matter of such difficulty that we attempted to find some derivative which would be more manageable. The bodies containing the aniline residue in place of one of the halogen atoms were found to be useless for our purpose, since they were decomposed by boiling in alkaline solution with the formation of phenylisocyanide, and the phenylamidocrotonolactone formed from them by reduction was also decomposed with the formation of aniline under the same conditions. It seemed probable that the corresponding derivatives containing the phenoxy group would prove to be much more stable. While we have not yet succeeded in replacing the bromine of the body $C_4H_2Br_2O_2$ directly by the phenoxy group, we have had no difficulty in preparing such a body by the reduction of the bromanhydride of the mucophenoxybromic acid which was described by Hill and Stevens.* The body thus formed was easily shown to be a phenoxybromcrotonolactone, since it dissolved in hot alkaline solutions with the formation of the salts of the corresponding oxy-acid. On acidifying the well cooled akaline solution the phenoxybromoxycrotonic acid was obtained, which was stable under ordinary conditions, but which was again converted into the lactone by heat. These results were fully confirmed by a study of the phenoxychlorcrotonolactone, which was prepared by the reduction of mucophenoxychlorylbromide. The position which the phenoxy group takes in entering mucobromic acid has already been shown with sufficient precision by Hill and Stevens, since a remarkably stable phenoxybromacrylic acid is readily formed from this product by the action of alkalies. The phenoxylactones containing halogen must therefore have the constitution





and the analogous bodies containing halogen alone the structure





The formation of these bodies from tribrom- and trichlorpyromucic acids seems to us to be most readily explained by assuming that a trisubstituted furfuran is first formed with the loss of carbonic dioxide :

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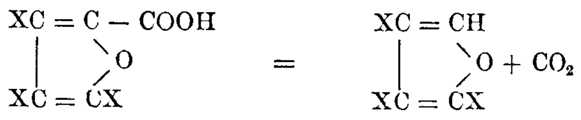
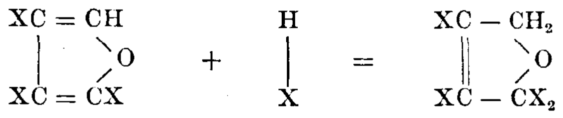
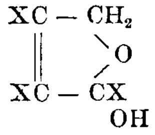
* These Proceedings, XIX. 262.



This then adds a molecule of haloid acid with the shifting of the double bond in a manner identical with that observed by v. Baeyer and Rupe* in the reduction of dichlormuconic acid:

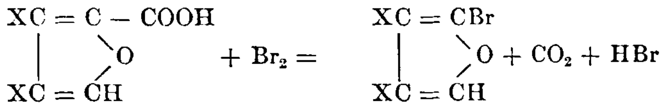


The addition product is then decomposed by water, giving the lactone. Possibly a molecule of water is directly added to the trisubstituted furfuran, giving



which would at once pass into the lactone by the loss of haloid acid.

The conversion of the βγ-dibrompyromucic acid into the dibromcrotonolactone, and of the βγ-dichlorpyromucic acid into the corresponding dichlorcrotonolactone by the action of bromine in aqueous solution likewise finds its explanation in the formation of a trisubstituted furfuran. In aqueous acid or alkaline solution the carboxyl of the substituted pyromucic acids is readily eliminated and replaced by bromine, as was first shown by Hill and Hartshorn † in the case of the δ-brompyromucic acid:



By the addition of water the substituted lactone is formed as before. We have shown that the bromanhydrides of mucobromic and mucochloric acids are also formed in this same reaction. This formation is evidently due to the addition of bromine to the trisubstituted furfuran and the decomposition of this product by water:

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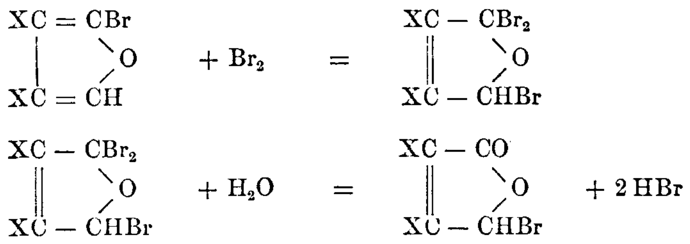
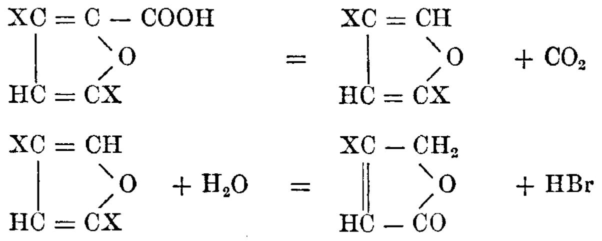
* Ann. Chem. u. Pharm., CCLVI. 25.

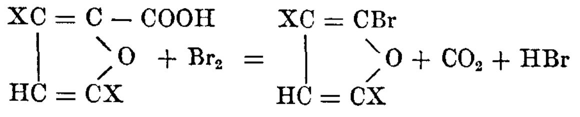
† Berichte d. deutsch. chem. Gesellsch., XVIII. 448.



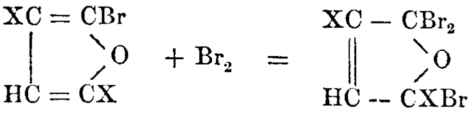
It has already been said that two isomeric monosubstituted crotonolactones may be made by appropriate means from the disubstituted pyromucic acids containing the halogens in the β and δ positions. By heating these substituted pyromucic acids with mineral acids the brom- and chlorcrotonolactones melting at 58° and 26° respectively may be made. The reaction is evidently perfectly analogous to the decomposition of the trisubstituted pyromucic acids under like conditions which has just been discussed. The carboxyl group is replaced by hydrogen with the loss of carbonic dioxide and the substituted furfuran thus formed then passes into the lactone as before:



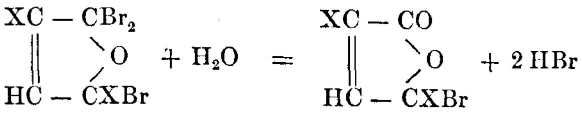
The β-substituted lactones which are thus formed may be made much more conveniently by the partial reduction of the disubstituted lactones. In order to prepare the monohalogenized crotonolactones with the halogen in the α position from the βδ-dichlor- and dibrompyromucic acids, derivatives of maleic acid must first be formed. The first step in the reaction is the formation of a trisubstituted furfuran through the replacement of the carboxyl by bromine:



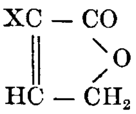
Through the addition of bromine with the shift of the double bond, as before,


XC = CBr
O
HC = CX
+ Br₂ =
XC — CBr₂
O
HC — CXBr

a body is formed which through the action of water yields the derivative of maleic acid:

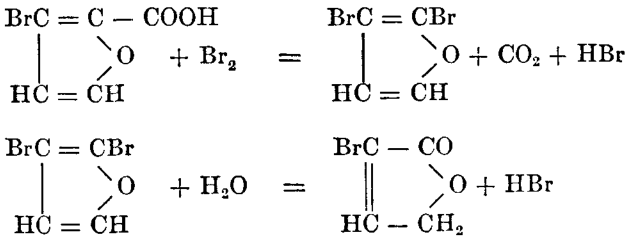

XC — CBr₂
O
HC — CXBr
+ H₂O =
XC — CO
O
HC — CXBr
+ 2 HBr

This in its turn gives the lactone by reduction:

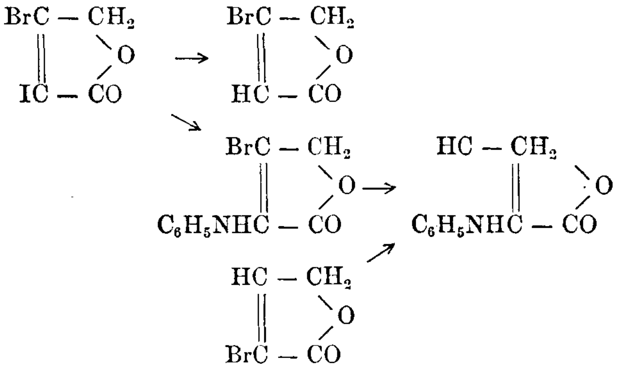

XC — CO
O
HC — CH₂

In the case of the $\beta\delta$-dibrompyromucic acid the tribromfurfuran, which should appear as the intermediate product in this reaction, has been isolated in a pure condition by Mr. W. M. Booth in this Laboratory, and been found to yield, when treated with bromine in aqueous solution, the brommaleylbromide described by Hill and Sanger.

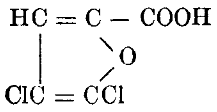
The α-bromcrotonolactone may also be formed by the action of bromine in aqueous solution upon β-brompyromucic acid. The reaction is evidently identical with that through which the dibromcrotonolactone is formed from $\beta\gamma$-dibrompyromucic acid. A dibromfurfuran is first formed, which by the fixation of water and the elimination of hydrobromic acid passes into the lactone:


BrC = C — COOH
O
HC = CH
+ Br₂ =
BrC = CBr
O + CO₂ + HBr
HC = CH
BrC = CBr
O
HC = CH
+ H₂O =
BrC — CO
O + HBr
HC — CH₂

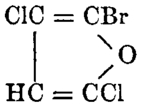
The isomerism observed in the monohalogenized crotonolactones must be due to the position of the halogen atoms, since, according to the views at present held concerning geometric isomerism, lactones can be formed from the maleinoid forms only. A definite proof that the halogen atoms in the α- and β-bromcrotonolactones are attached to different carbon atoms is easily given. The αβ-dibromcrotonolactone yields with hydriodic acid an iodine derivative which can be reduced to β-bromcrotonolactone. This same iodine compound gives with aniline a phenylamidobromcrotonolactone which on reduction is converted into the same phenylamidocrotonolactone that may be made by the action of aniline upon the α-bromcrotonolactone:

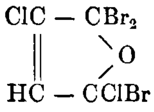


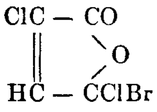
It is evident that the acid described by Hill and L. L. Jackson under the provisional name of the χ-dichlorpyromucic acid, since it readily gives the α-chlorcrotonolactone on decomposition with mineral acids, must in fact be the γδ-dichlorpyromucic acid, and its structure

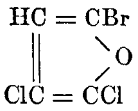


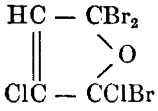
It is perhaps worthy of note that, although the βδ- and the γδ-dichlorpyromucic acids give the two isomeric chlorcrotonolactones when heated with acids, they give the same α-chlorcrotonolactone when they are treated with bromine in aqueous solution, and the resulting product it reduced. Evidently two isomeric dichlorbromfurfurans are first formed, which yield the corresponding addition products with bromine, but these addition products are attacked by water in such a way that in each case the chlorine is left in the α position with regard to the oxidized carbon:

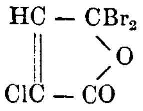




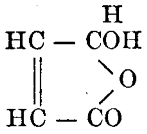




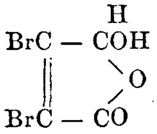




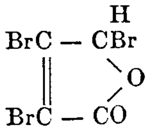
The close relationship between mucobromic acid and bodies which have thus been shown to be derivatives of crotonolactone naturally recalled the suggestions which had already been made as to the constitution of mucobromic acid itself. As early as 1882 Roser* pointed out that the so called fumaric aldehyde acid of Limpricht might in reality be an oxylactone,



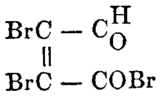
and afterward in 1887 Anschütz,† in his interesting and suggestive discussion of the constitution of maleic and fumaric acids, was led to the conclusion that mucobromic acid was an oxydibromcrotonolactone:



It was evident that the almost quantitative reduction of mucobromylbromide by such a reducing agent as stannous chloride in the cold was perfectly intelligible if the formula of this bromide were



while the formation of a lactone under these conditions from the bromanhydride derived from the aldehyde acid



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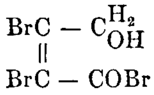
* Berichte d. deutsch. chem. Gesellsch., XV. 1523.

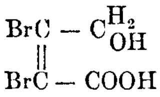
† Ann. Chem. u. Pharm., CCXXXIX. 161.

could hardly be explained except by assuming that the aldehyde group was itself first attacked, and the lactone then formed by the elimination of hydrobromic acid from the body



$$\begin{array}{l} \mathrm{BrC - C^{H_2}_{OH}} \\ \quad \| \\ \mathrm{BrC - COBr} \end{array}$$

This explanation seemed to us exceedingly improbable, and we furthermore showed by direct experiment that no perceptible amount of the dibromcrotonolactone could be formed by the action of stannous chloride and hydrochloric acid upon mucobromic acid itself, or by its reduction with zinc and acetic acid, while the alcohol acid



$$\begin{array}{l} \mathrm{BrC - C^{H_2}_{OH}} \\ \quad \| \\ \mathrm{BrC - COOH} \end{array}$$

which would be formed if the aldehyde group were readily reduced would certainly yield the lactone with facility. The ready formation of mucobromylbromide by the action of bromine at 100° upon the dibromcrotonolactone seemed equally conclusive, and the lactone formula for mucobromylbromide established. Since phosphorous tribromide converts mucobromic acid almost quantitatively into its bromanhydride, the lactone structure of mucobromic acid itself seemed to be proved. It can hardly be supposed that a bromide of the lactone formula could be formed from the aldehyde acid, for this would imply the replacement of the aldehyde oxygen through the phosphorous tribromide leaving the hydroxyl of the carboxyl group to form the lactone by the elimination of hydrobromic acid. Although Hill and O. R. Jackson * showed many years ago that mucobromic acid could readily be converted into dibrommaleic acid by means of argentic oxide, it was evident that even this mode of oxidation no longer warranted a definite conclusion as to its aldehyde character. We therefore thought it necessary to take up the study of the behavior of mucobromic and mucochloric acids, as well as the related acids containing the phenoxy group, toward hydroxylamine. We found that these four acids gave oximes with ease, and in studying more in detail the compounds formed from mucobromic acid we found that they were perfectly analogous to the bodies formed by the action of hydroxylamine upon opianic, phthalaldehydic, and pseudopianic acids as

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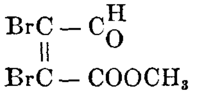
* These Proceedings, XVI. 186.

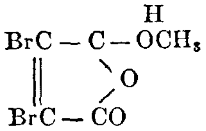
described by Lieberman,[*] Allendorf,[†] Racine,[‡] and Perkin.[§] Mucobromoxime is so unstable that it passes spontaneously into its anhydride, and can be formed only by the action of free hydroxylamine in aqueous solution. The anhydride is formed through the hydrochlorate in alcoholic solution, and by boiling this alcoholic solution or by heat alone is converted into dibrommaleinimide. The oxime or its anhydride is further converted into the acid ammonium salt of dibrommaleic acid by boiling it with water. The ready formation of oximes of perfectly normal character from mucobromic acid would in itself naturally be considered as establishing the aldehyde character of this acid. Still the difficulty in explaining the conversion of the bromanhydride of an aldehyde acid into a lactone by reduction with stannous chloride in the cold is so great that it seems to us more rational to suppose either that hydroxylamine acts directly upon an oxylactone of this type and that the ordinary oxime is then formed by molecular rearrangement, or that under the conditions of the reaction the hydroxylamine acts only through the fixation of a molecule of water, and the breaking of the lactone ring with formation of the aldehyde acid.

In this connection we were interested to know whether the esters of mucobromic acid would enter into reaction as readily as the free acid. While it seemed probable that the ester of the aldehyde acid of the form



$$\begin{array}{l}\mathrm{BrC-C}^{\mathrm{H}}_{\mathrm{O}} \\ \quad\ \| \\ \mathrm{BrC-COOCH_3}\end{array}$$

would be attacked by hydroxylamine quite as readily as the free acid, the ester formed from the oxylactone.



might well prove more refractory. Several years ago Lieberman[||] tried the behavior of the ethylester of opianic acid with hydroxylamine, and obtained only the opianic oxime anhydride. We have been able to find described no other experiments with the esters of the acids in question. Our own experiments with mucobromic acid, and its methyl ester, showed that the ester was attacked with much more difficulty. While mucobromic acid is rapidly converted into its oxime and oxime anhydride, we failed to discover any appreciable action when hydroxylamine is added to a solution of methyl mucobromate in methyl alcohol at ordinary temperatures even after the lapse of several days. On boiling, the methyl ester of mucobromoxime was formed, identical with the body formed by heating mucobromoxime with methyl alcohol. Further experiments in this direction can alone show whether the difference in behavior between the acids of this series and their esters is sufficiently general to warrant definite conclusions as to their structure. The action of phenylhydrazine upon mucobromic and mucochloric acids and their esters, which we hoped to study in detail, proved to yield bodies which were not suitable for investigation.

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[*] Berichte d. deutsch. chem. Gesellsch., XIX. 2278, 2923.

[†] Ibid., XXIV. 3264.

[‡] Ann. d. Chem. u. Pharm., CCXXXIX. 81.

[§] Journ. Chem. Soc., LVII. 1069.

[||] Berichte d. deutsch. chem. Gesellsch., XIX. 2926.

Many years ago Mr. C. W. Andrews, who was at that time an assistant in this Laboratory, made some experiments as to the action of aniline upon mucobromic acid and its ethyl ester, which he was unable to complete at the time, and which have never been published. He found that the reaction with mucobromic acid was complex, in that bromine was partially replaced by the aniline residue, and also that oxygen was eliminated by condensation. In marked contrast with this reaction was the behavior of ethyl mucobromate with aniline. One atom of bromine was here replaced, but the rest of the molecule remained unaltered, so that the body $C_4H_2Br(NHC_6H_5)O_3C_2H_5$ was formed in nearly theoretical quantity. It therefore seemed to us of interest to determine whether ethyl mucobromate would behave in an analogous way with ammonia. We found, however, in this case, that the reaction took a different course, and that the ethoxy group was first attacked. The body which is thus formed has the formula of the amide of mucobromic acid, but its behavior is in some respects anomalous. It dissolves readily in caustic alkalies, and may be reprecipitated unchanged by immediate acidification. It is but slowly converted into mucobromic acid by boiling with mineral acids, and with oxidizing agents it yields dibrommaleinimide. From mucochloric acid a body of similar properties was obtained.

αβ-DIBROMCROTONOLACTONE.

Although tribrompyromucic acid is little affected by boiling hydrochloric acid, it is quite readily decomposed, with the escape of carbonic dioxide, when heated to 130° with diluted sulphuric acid (sp. gr. 1.43), or when boiled with concentrated hydrobromic acid. The reaction seemed to be more neatly effected with the latter reagent, and we therefore heated tribrompyromucic acid with from four to five times its weight of concentrated hydrobromic acid with a return condenser. When no further escape of carbonic dioxide could be detected, the somewhat dark colored clear solution was cooled, and diluted with water. A heavy crystalline precipitate was thus thrown down, which could easily be purified by recrystallization from alcohol or ligroin. The crude product obtained in this way amounted to about half the weight of the tribrompyromucic acid taken. Analyses of the body after several recrystallizations from alcohol showed that it had the formula $C_4H_2Br_2O_2$. For the analyses of this dibromcrotonolactone, and of several of its derivatives, which we publish, we are indebted to Mr. H. N. Herman, who made a preliminary study of this body seme two years ago, but was unable to continue the investigation.

I. 0.2472 grm. substance gave 0.1788 grm. CO_2 and 0.0209 grm. H_2O.
II. 0.2394 grm. substance gave 0.3711 grm. AgBr.

	Calculated for $C_4H_2Br_2O_2$.	Found.	
		I.	II.
C	19.83	19.73	
H	0.83	0.94	
Br	66.12		65.96

This same body may also be made directly from mucobromic acid by the action of phosphorous iodide. Phosphorus is dissolved in five times its weight of carbonic disulphide, equivalent weights of iodine and mucobromic acid well ground together are then added, and the nearly solid mass heated on the water bath with reverse cooler. The reaction sets in slowly, and frequently only after a part of the carbonic disulphide has been allowed to escape through the cooler. With no solvent present the reaction is violent and yields little or no product. When the mass is completely liquefied, the rest of the carbonic disulphide is distilled off, the flask well cooled, and cold water added in not too small quantity. On shaking, the crude lactone separates in a granular condition. In this way it is easy to obtain a product which amounts to two thirds of the weight of the mucobromic acid taken, but it contains a decided percentage of iodine, and the preparation of pure dibromcrotonolactone from it is a matter of great difficulty. By fractional crystallization from various solvents we found it impossible to eliminate the iodine, but on distillation with steam the substance first carried over contained but little, and the percentage of iodine did not become large until about one half of the material taken had passed over. The material which had thus been partially purified by fractional distillation with steam, could not be further purified by recrystallization, but after boiling for some time with bromine water the iodine compound was oxidized, and a substance was then obtained which after several recrystallizations from alcohol possessed the properties and the composition of pure dibromcrotonolactone.

0.2439 grm. substance gave 0.3779 grm. Ag Br.

	Calculated for $C_4H_2Br_2O_2$.	Found.
Brm.	66.12	65. 93

The dibromcrotonolactone can much more readily be made from mucobromic acid by the reduction of its bromanhydride. Mucobromylbromide was described many years ago by Hill and O. R. Jackson,* who made it by the action of phosphoric pentabromide upon mucobromic acid. We have found that phosphorous tribromide is in many respects more advantageous for its preparation. The reaction runs somewhat slowly at 100°, but so smoothly that one molecule of the tribromide is sufficient for three molecules of mucobromic acid, and the yield is about 90 per cent of the theoretical amount. After the reaction is over the flask is well cooled, cold water is added, and the whole vigorously shaken until the oil which first separates solidifies in a granular form. The crude product melts at 54–55°, and by repeated recrystallization from small quantities of hot alcohol this melting point may be raised to 56–57°, one degree higher than the point given by Hill and O. R. Jackson. We attempted to purify the crude product by distillation *in vacuo*, but we found that the melting point was depressed rather than raised by this treatment. We have not further studied the change which is thus apparently brought about by distillation, for we soon found that a perfectly pure dibromcrotonolactone could be made directly from the mucobromylbromide, as it was precipitated by water, while it was difficult, if not impossible, to do this with the distilled substance of low melting point. Hydriodic acid, or zinc dust with glacial acetic acid, reduces the mucobromylbromide to the lactone, although the former reagent yields a product which contains iodine. A far more efficient and convenient reducing agent we found to be stannous chloride with hydrochloric acid, since this gives at once an essentially pure product in satisfactory quantity. Mucobromylbromide is added to an equal weight of stannous chloride dissolved in the same amount of concentrated hydrochloric acid. The reduction proceeds rapidly with the evolution of heat, although in working with small quantities the reaction is greatly facilitated by warming gently at first. When the melting point of the mucobromylbromide is reached, the flask must be well shaken until the oil has completely disappeared. As the solution cools the dibromcrotonolactone crystallizes out, and still more separates on dilution. The yield which may be obtained in this way amounts to from 75 to 80 per cent of the weight calculated from the mucobromylbromide taken, or about 70 per cent of that theoretically required by the mucobromic acid employed. A single recrystallization from alcohol is sufficient for its complete purification.

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* These Proceedings, XVI. 174.

Dibromcrotonolactone is very sparingly soluble in cold water, and dissolves in from 30 to 40 times its weight of boiling water. As the hot aqueous solution cools, the lactone crystallizes in small six-sided plates, or in pointed prisms crossing at an angle of 60°. From alcohol, in which it is somewhat sparingly soluble at ordinary temperatures, although very readily soluble on heating, it crystallizes in bundles of long friable prisms. From concentrated nitric acid it crystallizes in large, clear, brilliant oblique prisms. In boiling ligroin it dissolves somewhat sparingly on boiling, and as the solution cools the greater part of it separates in finely felted needles. It is readily soluble in chloroform or benzol, more sparingly soluble in ether or carbonic bisulphide. It melts at 90–91°, and boils under a pressure of 18 mm. at 145°. With steam it volatilizes rapidly. Although it is remarkably stable in acid solutions, it is easily attacked by alkalies. The alkaline hydrates dissolve it, forming deep yellow solutions, and at the same time alkaline bromides are formed. In studying the action of decinormal potassic hydrate in the cold, we have found that approximately two molecules of potassic hydrate are neutralized by each molecule of the lactone taken, while but one molecule of potassic bromide is formed, but have been able to isolate no definite products of the reaction. The lactone was not attacked by hydroxylamine; with aniline it yielded, with the elimination of bromine, the well crystallized aniline derivative, which will be described later. Phenylhydrazine also removed bromine, but gave no well characterized product.

Dibromfumaric Aldehyde of Toennies.

The melting point and other properties of the dibromcrotonolactone recalled a body of like composition which was obtained in 1879 by Toennies,* through the action of bromine water upon βγ-dibrompyromucic acid. He gives no analytical data to support his formula, and apparently had but small quantities of material at his disposal. From its behavior he considered the body to be the aldehyde of mucobromic acid, or the double aldehyde of dibromfumaric acid. In 1866 Hill and Sanger † again prepared this body from βγ-dibrompyromucic acid, but were unable to obtain it in satisfactory quantities, and hoped to return to it at some future time. A further study of the reaction has shown us that it is by no means simple in its nature. While we have been unable to obtain a satisfactory yield of the desired product, we have succeeded in preparing an amount amply sufficient for its identification, and at the same time we have isolated a second product of the reaction.

Preliminary experiments showed us that it was most advantageous to add about 20 per cent more than one molecule of bromine to the finely divided dibrompyromucic acid suspended in 20 times its weight of cold water. We therefore boiled 5 grm. of pure βγ-dibrompyromucic acid with 100 c.c. of water, and quickly cooled the solution in order to obtain the acid in a finely divided condition. When the temperature reached 16°, 1.2 c.c. of bromine were added, and the whole well shaken. The color of the bromine gradually faded, but when it had completely disappeared a considerable amount of a well crystallized body remained undissolved. Instead of allowing the solution to stand over night, as Hill and Sanger had done, we filtered out the insoluble substance at the end of three hours, and extracted the colorless aqueous solution thoroughly with ether. The ethereal extract left on distillation a syrupy residue, which partially solidified on standing over night *in vacuo* over sulphuric acid. The crystals when thoroughly drained upon the pump and pressed weighed 0.85 grm. Two crystallizations from small quantities of hot alcohol yielded 0.65 grm. of substance, which melted at 90–91°, and showed the characteristic behavior of the dibromcrotonolactone. In order to identify it with precision, we converted it into the α-iod-β-bromcrotonolactone, which is fully described later, by heating it with hydriodic acid, and found the product to melt at the proper point, 118–119°. On reduction with zinc and acetic acid it yielded the β-bromcrotonolactone melting at 57–58°, and with aniline the α-phenylamido-β-bromcrotonolactone with its characteristic properties, both of which bodies, as we shall afterwards show, may be made in the same way from the dibromcrotonolactone. As we shall show more fully later, we were unable to confirm the statement of Toennies that the dibromcrotonolactone could easily be converted into mucobromic acid by oxidation with chromic acid. By the action of bromine in aqueous solution a part of the βγ-dibrompyromucic acid had been converted into dibromcrotonolactone, according to the equation given by Toennies,

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* Berichte d. deutsch. chem. Gesellsch., XII. 1202.

† These Proceedings, XXI. 172.

$$C_5H_4Br_2O_3 + Br_2 + H_2O = C_4H_2Br_2O_2 + CO_2 + 2\,HBr.$$

The viscous oil which had been drained from the crystalline product deposited a few more crystals of the lactone on long standing, but we have not yet examined it further. The insoluble matter, which had been removed by filtration before the extraction with ether, was washed with a dilute solution of sodic carbonate. But a small amount dissolved, and upon acidification 0.2 grm. of a sparingly soluble acid was precipitated, which melted at 189–190°, and was evidently unaltered dibrompyromucic acid. The residue, insoluble in the alkaline solution, weighed 1 grm., and consisted chiefly of mucobromylbromide. It gave in alcoholic solution a deep blue evanescent color on the addition of sodic carbonate, and one crystallization from alcohol was sufficient to raise the melting point to 56–57°. A part of the dibrompyromucic acid had therefore been decomposed according to the equation

$$C_5H_4Br_2O_3 + 2\,Br_2 + H_2O = C_4HBr_3O_2 + CO_2 + 3\,HBr.$$

Mucobromylbromide is so slowly attacked by water that little mucobromic acid could have been formed under the conditions chosen; but it is found in abundance when the product of the reaction stands for a long time in dilute solution. The alcoholic mother liquors obtained from the recrystallization of the mucobromylbromide were evaporated, and the residue boiled with water under a reverse cooler until the bromanhydride had been converted into mucobromic acid. A small amount of insoluble material was then left, which had the odor of tetrabromfurfuran, but we were unable to identify it with precision. A preliminary experiment under essentially the same conditions had already yielded us a crystalline body, which was proved by its melting point (64°), and other characters, to be tetrabromfurfuran. Hill and Sanger * had previously found that this substance was formed in considerable quantities when bromine was gradually added to the dibrompyromucic acid suspended in water.

Action of Oxidizing Agents.

As we already have said, dibromcrotonolactone may be crystallized without alteration from concentrated nitric acid, but on long boiling it is slowly oxidized, and mucobromic acid or dibrommaleic acid formed. Even fuming nitric acid attacks it with difficulty, and after boiling for half an hour the greater part of the lactone taken may be recovered unchanged. We dissolved the lactone in 8 times its weight of concentrated nitric acid (sp. gr. 1.42), and boiled the solution for three hours under a reverse condenser. The unaltered lactone was then driven off with steam, and the acid solution evaporated to small volume. On cooling, mucobromic acid separated in abundance, which melted at 119–120°, after recrystallization from hot water. Even after boiling for six hours with concentrated nitric acid the oxidation was far from complete, but it was then easy to establish the formation of dibrommaleic acid through the melting point (114–115°) of its anhydride. On boiling the lactone with bromine water, it is slowly converted into mucobromic acid. The reaction may be hastened greatly by using concentrated hydrobromic acid as a solvent, and the oxidation is then completed in a comparatively short time. The mucobromic acid which we obtained, when recrystallized from water, melted at 120–121°. With chromic acid the action is also very slow, and we have been unable to identify any products of the oxidation except carbonic dioxide. If an amount of chromic acid was used which corresponded to one atom of oxygen for each molecule of the lactone, several hours at 100° were needed for the complete reduction of the chromic acid. On distillation large quantities of the unaltered lactone were obtained (melting point 90–91°), and the retort residue, when evaporated to small volume, deposited nothing on cooling. This residue was therefore extracted with ether, the ethereal extract shaken with a dilute solution of sodic carbonate, and this alkaline solution immediately acidified with hydrochloric acid, and again extracted with ether. The ether then left upon evaporation a small syrupy residue, which was strongly acid to test paper. After standing for several days, several minute clusters of rhombic plates could be seen under the microscope. In appearance they closely resembled mucobromic acid, but they were insufficient in quantity even for a melting point determination. Since the dibromcrotonolactone reduced an ammoniacal solution of argentic nitrate on heating, we made one attempt to effect its oxidation with argentic oxide. On boiling an aqueous solution of the lactone with a large excess of well washed argentic oxide, metallic silver was formed, but at the same time argentic bromide in large quantity. An approximate quantitative determination showed that 87.5 per cent of the total bromine contained in the lactone had been converted into argentic bromide. After a careful search we failed to find any products of the oxidation except an amount of dibrommaleic acid, which was just sufficient for its complete identification through the microscopic appearance of its barium salt and the melting point of its anhydride, 114–115°.

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* These Proceedings, XXI. 172.

Action of Bromine.

Dibromcrotonolactone is not attacked by bromine at ordinary temperatures, but at 100° substitution is quite rapidly effected. If equal molecules of bromine and the lactone are taken, a colorless oil is obtained after several hours' heating, which on standing gradually solidifies, and the crystalline solid may be purified by recrystallization from small quantities of alcohol. The substance which was thus obtained melted at 56–57°, and gave with alkalies *in alcoholic solution* the characteristic blue color described by Hill and O. R. Jackson.* Mucobromylbromide had therefore been formed from the dibromcrotonolactone according to the equation

$$C_4H_2Br_2O_2 + Br_2 = C_4HBr_3O_2 + HBr.$$

When heated with an excess of bromine further substitution is effected and a product is obtained in which both the hydrogen atoms of the dibromcrotonolactone are replaced. For the preparation of this body we heated equal molecules of mucobromylbromide and bromine in sealed tube at 125–130°. At this temperature the reaction proceeds rapidly, but it is also completed at 100° on longer heating. The colorless oil which we obtained gave no blue color in alcoholic solution with sodic carbonate, and on standing gradually solidified. The carefully pressed solid proved to be extremely soluble in alcohol, ether, chloroform, benzol, or carbonic disulphide, but it was somewhat more sparingly soluble in ligroin and could be purified by recrystallization from this solvent. The percentage of bromine which the substance contained corresponded to the formula $C_4Br_4O_2$.

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* These Proceedings, XVI. 175.

I. 0.1685 grm. substance gave 0.3177 grm. AgBr.
II. 0.1884 grm. substance gave 0.3552 grm. AgBr.

	Calculated for $C_4Br_4O_2$.	Found.	
		I.	II.
Br	80.00	80.23	80.20

This substance crystallizes from ligroin in clustered leaflets which melt at 58–59°. It has a strong suffocating odor like that of the acid bromanhydrides. When heated with water it is slowly dissolved and the solution then contains dibrommaleic acid. The acid was as usual identified by the crystalline form of the barium salt, and by the melting point (114–115°) of its anhydride. On treating the body with stannous chloride and hydrochloric acid the dibromcrotonolactone is again formed by reduction. The mode of formation, the composition, and the behavior of this body justify the conclusion that it is the unsymmetrical form of dibrommaleylbromide. Its behavior will be further studied in this Laboratory. We have made many unsuccessful attempts to prepare an identical or an isomeric body directly from dibrommaleic acid. We have tried the action of phosphoric pentabromide upon dibrommaleic anhydride at temperatures which varied from 100° to 225°, and either obtained the unaltered anhydride, or else carbonization ensued. We were equally unsuccessful in our attempts to prepare such a product through the salts of the acid.

Action of Aniline.

Aniline reacts upon the $\alpha\beta$-dibromcrotonolactone at ordinary temperatures and forms α-phenylamido-β-bromcrotonolactone. This substance is most readily prepared by dissolving the lactone in twenty parts of alcohol, diluting this solution with an equal weight of water, and then adding somewhat more than two molecules of aniline. On standing long needles of the aniline derivative separate in abundance, which may be purified by recrystallization from sixty per cent acetic acid, and afterward from alcohol.

I. 0.2570 grm. substance gave 0.4426 grm. CO_2 and 0.0763 grm. H_2O.
II. 0.2393 grm. substance gave 0.1775 grm. AgBr.
III. 0.2727 grm. substance gave 13.4 c.c. of moist nitrogen at 21° and under a pressure of 763 mm.

	Calculated for $C_{10}H_8BrNO_2$	Found. I.	II.	III.
C	47.24	46.97		
H	3.15	3.30		
Br	31.50		31.56	
N	5.51			5.63

α-Phenylamido-β-bromcrotonolactone is almost insoluble in ether, carbonic disulphide, or ligroin, but dissolves somewhat more readily in boiling benzol or chloroform. It is somewhat sparingly soluble even in boiling alcohol, still less freely in boiling water, and as the solutions cool is deposited in each case in long brilliant needles. In hot glacial acetic acid the substance dissolves readily; from chloroform it crystallizes in thin transparent plates. When slowly heated it melts with decomposition at about 165°, but if the capillary tube containing the substance is plunged into the heated bath it melts promptly at 186–187° and immediately decomposes. In alkaline solutions it dissolves readily on warming, and if the solution be quickly cooled it crystallizes out apparently unchanged, but on heating for a longer time decomposition ensues, as the strong odor of phenylisocyanide shows. By the action of sodium amalgam bromine is removed and α-phenylamidocrotonolactone, which we shall describe later, is formed. We have been unable to replace the second atom of bromine by heating with an excess of aniline.

Action of Hydriodic Acid.

When αβ-dibromcrotonolactone is dissolved in ordinary distillable hydriodic acid and the solution is boiled for a short time, or heated for a longer time at 100°, one atom of bromine is replaced by iodine, and as the solution cools the α-iod-β-bromcrotonolactone separates in long prisms. This same body is also formed by the action of phosphorous iodide upon mucobromic acid or when hydriodic acid acts upon mucobromylbromide, and it may easily be made the chief product of the latter reaction. For analysis it was recrystallized from alcohol.

I. 0.2393 grm. substance gave 0.1453 grm. CO_2 and 0.0229 grm. H_2O.
II. 0.1874 grm. substance gave 0.2747 grm. AgBr + AgI.
III. 0.2031 grm. substance gave 0.2978 grm. AgBr + AgI.

	Calculated for $C_4H_2BrIO_2$.	Found. I.	II.	III.
C	16.61	16.56		
H	0.69	1.05		
Br + I	71.63		71.76	71.78

The α-iod-β-bromcrotonolactone is quite readily soluble in benzol or chloroform, more sparingly soluble in ether, carbonic disulphide, or ligroin. It dissolves freely in boiling alcohol, and as the solution cools it is deposited in quite large, oblique, colorless prisms, which gradually change color on exposure. With steam it distils with difficulty. The melting point of most preparations of this substance we have found to be constant at 118–119°. Still we were frequently unable to raise by recrystallization alone the melting point of material which melted at too low a temperature, and on one occasion a preparation made in the usual way melted one degree higher at 119–120°. Toward aqueous alkalies this substance behaves like the corresponding bromine derivative, an alkaline iodide being formed in the decomposition. Concentrated nitric acid or bromine water on boiling liberates iodine. When heated with one molecule of dry bromine in sealed tube at 100°, iodine is also liberated, and but a small quantity of hydrobromic acid is formed. With aniline in dilute alcoholic solution it yields the α-phenylamido-β-bromcrotonolactone, which has already been described, although not quite as smoothly as the dibromlactone, since dark-colored viscous products, which we have not further examined, are formed at the same time. On reduction with zinc dust and glacial acetic acid, the β-bromcrotonolactone melting at 58°, which we shall presently describe, was formed. After dilution with water the acid solution was extracted with ether, the ethereal extract washed with a dilute solution of sodic carbonate, and the crystalline residue obtained by the evaporation of the ether recrystallized several times from small quantities of alcohol. The body thus obtained had the properties of the β-bromcrotonolactone, melted at 57–58°, contained but an unweighable trace of iodine, and gave on analysis the required percentage of bromine.

0.2078 grm. substance gave 0.2407 grm. AgBr.

	Calculated for $C_4H_3BrO_2$.	Found.
Br	49.08	49.27

When the iodbromcrotonolactone was boiled with hydriodic acid the separation of iodine soon ensued. After long boiling with the addition of red phosphorus, although traces of volatile products, which had the odor of fat acids, had been formed, the main product of the reduction was a viscous oily body, which could be extracted by ether from the diluted solution, but from which we were unable to prepare any material suitable for analysis. With distillable hydriodic acid and red phosphorus in sealed tubes at temperatures below 180° we obtained substantially the same result, while prolonged heating at 200° brought about decomposition. We had no better success when we employed hydriodic acid saturated at 0°, although in this case decomposition set in at a lower temperature.

β-BROMCROTONOLACTONE.

When βδ-dibrompyromucic acid is boiled with concentrated hydrobromic acid, it is slowly decomposed, carbonic dioxide is evolved, and β-bromcrotonolactone is formed. The reaction does not run as smoothly as it does with tribrompyromucic acid, and more or less carbonization ensues. When the reaction appears to be completed, the dilution of the dark brown solution usually precipitates a small amount of dark-colored unaltered acid, but no lactone is thus thrown down. The filtered solution is then extracted with ether, the ethereal extract washed with a dilute solution of sodic carbonate, and dried with calcic chloride. The residue left after distilling off the ether gradually solidifies on standing, and the crude product, which amounts to about one quarter of the dibrompyromucic acid taken, may be recrystallized from small quantities of alcohol or from ether. The same body may be prepared much more conveniently by the reduction of the αβ-dibromcrotonolactone with zinc dust and acetic acid. The dibromcrotonolactone is suspended in its own weight of 80 per cent acetic acid, and somewhat more than the calculated weight of zinc dust is then added with careful cooling. At first the reduction proceeds rapidly with the evolution of heat, but several hours at ordinary temperatures are necessary for its completion. When the zinc has nearly disappeared the viscous solution is warmed, filtered, and the clear filtrate cautiously diluted with water. The bromlactone is thus precipitated as an oil, which after cooling and shaking soon solidifies in the form of colorless feathery crystals. The precipitated lactone amounts to 45 per cent of the weight of the dibromcrotonolactone taken, and somewhat more may be obtained by extracting the mother liquor with ether.

I. 0.2417 grm. substance gave 0.2609 grm. CO_2 and 0.0440 grm. H_2O.
II. 0.1913 grm. substance gave 0.2214 grm. AgBr.

	Calculated for $C_4H_3BrO_2$.	Found. I.	Found. II.
C	29.45	29.44	
H	1.86	2.02	
Br	49.08		49.24

The β-bromcrotonolactone is readily soluble in alcohol, chloroform, benzol or carbonic disulphide. It is decidedly less soluble in ether, and very sparingly soluble in ligroin. From small quantities of alcohol it crystallizes in colorless clustered prisms, from ether by slow evaporation in large transparent six-sided plates. It is quite readily soluble in hot water, and as the hot aqueous solution cools it separates in clear obliquely truncated prisms. It melts at 58°, and boils under a pressure of 18 mm. at 140°. It distils with steam, although with some difficulty. Aqueous alkalies dissolve it with the formation of a deep yellow color, and the solution then contains an alkaline bromide. In dilute alcoholic solution aniline also removes bromine, but forms at the same time a dark-colored viscous oil, from which we have been able to isolate no crystalline product.

Action of Bromine.

β-Bromcrotonolactone is but slowly attacked by bromine in the cold. If one molecule of bromine is added to the powdered lactone, a clear deep red solution is soon obtained, but the color fades so slowly that several days are required to complete the reaction at ordinary temperatures. On opening the tube a small quantity of hydrobromic acid escaped, but the weight of the crystalline product was substantially the same as that of the materials employed. After several recrystallizations from alcohol an analysis also showed that the substance had been formed by the addition of bromine.

0.2965 grm. substance gave 0.5175 grm. AgBr.

	Calculated for $C_4H_3Br_3O_2$.	Found.
Br	74.30	74.27

This body, which from the mode of its formation must be the $\alpha\beta_2$-tribrombutyrolactone, is readily soluble in alcohol, ether, benzol, carbonic disulphide, or chloroform, but is more sparingly soluble in ligroin. From alcohol it is deposited in large, well formed, brilliant prisms, which melt at 63–64°. On boiling with water a part distils unchanged, but decomposition soon sets in, carbonic dioxide is evolved, and hydrobromic acid is formed. If the β-bromcrotonolactone is heated to 100° with one molecule of bromine, the color of the bromine soon disappears, but at the same time hydrobromic acid is formed in considerable quantities. With an excess of bromine at 100° mucobromylbromide is formed in abundance. The product which we obtained melted at 56–57°, gave in alcoholic solution a deep blue color with sodic carbonate, and when heated with water yielded mucobromic acid.

Action of Oxidizing Agents.

We have been unable to obtain any characteristic products by the oxidation of the β-bromcrotonolactone. On boiling with concentrated nitric acid oxidation takes place, but carbonic dioxide is evolved in abundance, and no other definite products were isolated. When heated with bromine in aqueous solution the addition product is apparently formed at first, but on boiling this is soon broken up with the evolution of carbonic dioxide. We also noticed in this case the formation of a small amount of a highly crystalline body which on recrystallization from alcohol formed long lustrous prisms. The melting point (54°), the camphor-like odor, and other physical properties, render it extremely probable that this substance was pentabromethan, but it was insufficient in quantity for analysis. The aqueous solution upon evaporation gave a small viscous residue, from which on long standing a few microscopic rhombic plates separated which appeared to be mucobromic acid.

α-BROMCROTONOLACTONE.

Since the γδ dibrompyromucic acid is as yet unknown, and the α bromine atom of the αβ-dibromcrotonolactone seems always to be first attacked by reagents, it was necessary to try some new method for the preparation of the α-bromcrotonolactone. It occurred to us that it was by no means impossible that it might be made from brommaleylbromide, since the chloranhydrides of similar dibasic acids were known in several instances to yield lactones on reduction. We soon found on trial that our conjecture was correct. Hill and Sanger [*] had already shown that a crystalline body having the formula $C_4HBr_3O_2$, and yielding monobrommaleic acid when decomposed by water, could be made from βδ-dibrompyromucic acid by the action of bromine in aqueous solution. This brommaleylbromide we therefore prepared, although we modified slightly the method of preparation in that we dissolved the βδ-dibrompyromucic acid in the requisite amount of a dilute solution of sodic carbonate, and added to this feebly alkaline solution slightly more than two molecules of bromine. We attempted to purify the product by distillation *in vacuo*, and found that it boiled without noticeable decomposition at 124–125° under a pressure of 17 mm. The distillate remained liquid for a long time, and then but partially solidified with the separation of the original substance. The solid portion melted at 54–55°, while the brommaleylbromide, according to Hill and Sanger, melts at 55–56°. The liquid portion was much more readily attacked by cold water than the original substance, and gradually dissolved, leaving about one third its weight of the crystalline solid, which had been held in solution. In the aqueous solution was found monobrommaleic acid melting at 130°, and by evaporation monobromfumaric acid melting at 178° was obtained. These facts seem to us sufficient to show that we had in our hands two different bodies, each of which showed the properties of a brommaleylbromide. The relation between these bodies will be more fully investigated. For the preparation of the α-bromcrotonolactone we found that no purification of the crude product was necessary.

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[*] These Proceedings, XXI. 166.

The brommaleylbromide is readily reduced by a solution of stannous chloride in strong hydrochloric acid, but the isolation of the lactone which is formed is difficult. Although it is volatile with steam, it distils slowly, remains dissolved in the distillate, and must be extracted from the dilute solution by ether. We have found it more convenient to use zinc and acetic acid for the reduction. The brommaleylbromide is suspended in one and a half times its weight of 80 per cent acetic acid, and somewhat more than the calculated amount of zinc dust added with careful cooling. The reaction is at first attended with great evolution of heat, and the zinc dust must be slowly added. After the completion of the reaction the addition of water to the filtered solution precipitates but a small part of the lactone, and the solution must be thoroughly extracted with ether. The ethereal solution, when washed with a dilute solution of sodic carbonate and dried with calcic chloride, leaves upon distillation the beautifully crystalline α-bromcrotonolactone contaminated with but small amounts of oily impurities. The thoroughly pressed substance may most readily be purified by recrystallization from ether. This same α-bromcrotonolactone is also formed by the action of bromine in aqueous solution upon β-brompyromucic acid. As is the case with the analogous reaction by which αβ-dibromcrotonolactone is formed from βγ-dibrompyromucic acid, the yield is small, and we have as yet merely satisfied ourselves of the identity of the product through its physical properties.

0.2000 grm. substance gave 0.2304 grm. AgBr.

	Calculated for $C_4H_3BrO_2$.	Found.
Br	49.08	49.01

The α-bromcrotonolactone is readily soluble in alcohol or chloroform, somewhat more sparingly soluble in ether or benzol, sparingly soluble in cold carbonic disulphide, more readily in hot, and sparingly soluble in ligroin. It dissolves quite freely in boiling water and distils slowly with steam. It crystallizes in long transparent prisms of adamantine lustre, which melt at 77°. It dissolves in alkalies with a deep yellow color and the formation of an alkaline bromide. It also reduces argentic nitrate in ammoniacal solution on boiling. With aniline, when dissolved in dilute alcohol, it gives the well crystallized α-phenylamidocrotonolactone. The α-bromcrotonolactone appeared to be identical with the body of like formula and the same melting point which Hill and Sanger[*] obtained in small quantity as a by-product in the preparation of the dibrompyromucic acids by the action of alcoholic sodic hydrate upon pyromucic tetrabromide. Still their statements concerning the behavior of their substance toward bromine were at variance with our own observation, and a more vigorous proof of the identity of the two bodies was necessary. Fortunately a small amount (0.125 grm.) of their old preparation still remained, and we were able to establish its identity with our own product, since it gave with aniline the same α-phenylamidocrotonolactone melting at 217–218°,[†] and was attacked by bromine and water in the same way.

Action of Bromine.

α-Bromcrotonolactone is very slowly attacked by dry bromine at ordinary temperatures. If one molecule is added, the lactone does not dissolve at first, and the color of the bromine remains apparently unchanged for several days. The reaction then seems to proceed more rapidly, and at the end of the sixth day we found that the color had faded completely. The tube then opened with pressure, and a large amount of hydrobromic acid escaped. Substitution had evidently taken place, and the weight of the liquid product corresponded precisely with that which would theoretically be required by the replacement of one hydrogen atom by bromine. The product of the reaction remained for a long time liquid, and its alcoholic solution gave but a greenish color on the addition of sodic carbonate. After long standing in desiccator a few large clear crystals appeared, which from their melting point (90–91°) and other characters were shown to be the αβ-dibromcrotonolactone. After distilling with steam, in order to remove the dibromcrotonolactone, the aqueous solution left on evaporation a viscous residue. After long standing in desiccator a few microscopic rhombic plates appeared, which were doubtless mucobromic acid. On repeating this experiment later, when the mean temperature of the room was much higher, the reaction was completed in about half the time, the product gave a decided blue color in alcoholic solution with sodic carbonate, showing the formation of mucobromylbromide, but on long standing crystals of dibromcrotonolactone were also formed. On heating with two molecules of bromine for several hours at 100°, mucobromylbromide is formed in quantity. The product gradually solidified on standing, gave an intense blue color with sodic carbonate, and after recrystallization from alcohol melted at 56–57°.

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[*] These Proceedings, XXI. 158.

[†] See page 31.

Action of Oxidizing Agents.

Concentrated nitric acid oxidizes the α-bromcrotonolactone without much difficulty at 100°. Carbonic dioxide is freely evolved, and a small quantity of a volatile oil is formed, which has a suffocating, sharp odor, and contains both nitrogen and bromine. We were unable to isolate other characteristic products of the reaction. With bromine in aqueous solution we had somewhat better success. The reaction progressed slowly, but after boiling for several hours with an excess of bromine a small amount of an oily product had been formed which was not further examined. The aqueous solution upon evaporation gave characteristic crystals of mucobromic acid, which, after rerecrystallization from water, melted at 120–121°. The weight of mucobromic acid thus obtained was, however, barely 20 per cent of the theoretical amount, and carbonic dioxide was also formed in the reaction. Hill and Sanger had found that the body which they described as having the composition of a bromcrotonolactone and melting at 77° was converted by bromine and water into an amorphous substance insoluble or sparingly soluble in all common solvents. Two experiments which we tried with small quantities of their old preparation failed to confirm their statements. It gave precisely the same results which we had already obtained with the α-bromcrotonolactone. The yield of mucobromic acid given by the reaction is so small, and the quantity of the old material at our disposal was so limited, that we were unable to purify our product sufficiently for a sharp determination of the melting point. Its appearance and behavior left no doubt as to its identity.

Action of Aniline.

If aniline is added to a solution of the α-bromcrotonolactone in dilute alcohol, the bromine is gradually displaced at ordinary temperatures, and the corresponding phenylamidocrotonolactone is formed. The somewhat dark-colored crystalline mass, which separates after the lapse of twenty-four hours, may be purified by recrystallization from glacial acetic acid, and afterward from alcohol. The α-chlorlactone which was described by Hill and L. L. Jackson,* and of which we shall speak later, also reacts as readily with aniline, and naturally gives the same product. The same body may furthermore be made, although with more difficulty, by the reduction of the α-phenylamido-β-bromcrotonolactone. The elimination of the bromine takes place so slowly in acid solution that we have found it more advantageous to employ sodium amalgam with dilute alcohol, and to allow the reduction to proceed in alkaline solution at ordinary temperatures. Although more or less decomposition of the phenylamidobromcrotonolactone takes place, as the strong odor of phenylisocyanide which is developed shows, a satisfactory product is obtained in this way. The finely powdered α-phenylamido-β-bromcrotonolactone is suspended in 50 times its weight of about 60 per cent alcohol, and an excess of sodium amalgam containing 2 per cent of metallic sodium is added. The substituted lactone gradually goes into solution, and we usually have found the reduction complete at the end of four or five hours. The clear solution is then acidified with acetic acid, the alcohol driven off upon the water bath, and the crystalline product which separates recrystallized from glacial acetic acid. Occasionally we have found it necessary to treat the product a second time with sodium amalgam in order to remove the last traces of bromine.

I. 0.1991 grm. substance gave 0.4996 grm. CO_2 and 0.0962 grm. H_2O.

II. 0.2114 grm. substance gave 14.9 c.c. of moist nitrogen at 21°.3 and under a pressure of 754 mm.

	Calculated for $C_{10}H_9NO_2$.	Found. I.	Found. II.
C	68.57	68.42	
H	5.14	5.36	
N	8.00		7.94

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* These Proceedings, XXIV. 353.

α-phenylamidocrotonolactone is very sparingly soluble even in boiling water. It dissolves quite readily in boiling alcohol, more sparingly in cold, and very sparingly in hot benzol or chloroform; in ether, ligroin, or carbonic disulphide, it is nearly insoluble. It is readily soluble in hot glacial acetic acid, and crystallizes on cooling in feather-formed aggregations of branching needles. The melting point of the substance varies somewhat according to the rapidity with which it is heated; but with proper care to avoid long heating it was found to melt quite sharply at 217–218°, although decomposition ensued on further heating. Material made from the α-chlor- and α-bromlactones, as well as by the reduction of the phenylamidobromlactone, showed identically the same behavior on heating, and when tested side by side in the same bath melted at the same temperature. The body dissolves readily in hot concentrated hydrochloric acid, but aniline seems to be formed at once. In hot alkaline solutions it dissolves somewhat more readily than in water, and if such a hot solution is quickly cooled it separates apparently unchanged. On longer heating decomposition sets in. A solution of the body in hot dilute baric hydrate was boiled for a short time and distilled. The distillate contained aniline in abundance, as was shown by the formation of tribromaniline melting at 118–119°. At the same time baric carbonate had been precipitated, and in solution was found a barium salt which was extremely soluble in water, was precipitated by alcohol from the concentrated aqueous solution in an amorphous form, and was left as a brownish varnish upon evaporation.

REDUCTION OF THE αβ-DIBROMCROTONOLACTONE TO CROTONOLACTONE.

When dibromcrotonolactone is heated to 100° with dilute sulphuric acid and granulated zinc, it is rapidly reduced, and at the end of several hours the reduction is complete. It was easy to prove by quantitative determinations that all the bromine of the original substance had been converted into hydrobromic acid, and the behavior of the solution toward decinormal potassic hydrate also showed that it contained a lactone in nearly theoretical quantity. We found it practically impossible to extract the lactone from aqueous solution, and we therefore distilled this solution in a current of steam. The distillate which we obtained was feebly acid, but it also contained a small quantity of a lactone, which, however, we found by titration to be relatively large in proportion to the free acid. The amount of free acid varied very much in our preparations, and apparently disappeared entirely, if during the reduction too large an excess of sulphuric acid was not used. With ordinary care the free acid did not correspond to as much as one tenth of the total alkali which was neutralized on boiling, and we were unable to increase that amount beyond one fifth by any modification of the mode of reduction. Our determinations furthermore showed that each litre of distillate could contain but 1.25 grm. of crotonolactone if this body had really been formed by reduction. We made many fruitless attempts to isolate the crotonolactone from this dilute aqueous solution, and since our main object was to establish beyond question the lactone nature of the dibromcrotonolactone from which it had been formed, we proceeded at last to prepare from the solution a salt of the corresponding oxycrotonic acid. To the dilute lactone solution we added slightly more than the required amount of baric hydrate, heated the alkaline solution to boiling, precipitated after the lapse of some time the slight excess of baric hydrate by carbonic dioxide, and evaporated to small volume the filtered solution. We obtained in this way a somewhat brown syrupy residue, which on drying yielded a hard varnish. For its purification it was dissolved in a small amount of water, and alcohol added until a portion of the salt had been precipitated. The filtered solution was then concentrated by evaporation, a trace of a haloid barium salt removed by the cautious addition of argentic carbonate, and the clear solution evaporated upon the water bath. After drying for some time at 100°, the gummy salt became sufficiently friable to enable us to powder it, and it was then thoroughly dried at 100°. A complete analysis showed that this salt had the composition of a baric oxycrotonate. The second determination of carbonate was made in the wet way by the method of Messinger,* the first by the more usual method with potassic dichromate in open tube.

I. 0.1961 grm. salt gave 0.2044 grm. CO_2 and 0.0694 grm. H_2O.
II. 0.1432 grm. salt gave 0.1503 grm. CO_2.
III. 0.2414 grm. salt gave 0.1655 grm. $BaSO_4$.

	Calculated for $Ba(C_4H_5O_3)_2$.	Found. I.	II.	III.
C	28.30	28.42	28.63	
H	2.95	3.93		
Ba	40.44			40.33

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* Berichte d. deutsch. chem. Gesellsch., XXI. 2910.

The formation of the crotonolactone through the reduction of the dibromcrotonolactone was thus established. Since the salts of the oxycrotonic acid all seemed to possess the same uninviting properties, and our main end was already reached, we made no further study of them.

αβ-DICHLORCROTONOLACTONE.

The αβ-dichlorcrotonolactone may be prepared most easily by the reduction of mucochlorylbromide. This body, which has not yet been described, was readily made by the action of phosphorous tribromide upon mucochloric acid. The reaction ran perfectly smoothly, and but little more than one molecule of phosphorous tribromide was needed for complete reaction with three molecules of mucochloric acid. After heating at 100° until the liquefied product grew turbid with the separation of phosphorous acid, the flask was well cooled, and cold water added with constant shaking. The oil which separated gradually solidified, and the granular product which was obtained could readily be collected by filtration. As in the preparation of mucobromylbromide we have found it easy to obtain 88–90 per cent of the theoretical yield, and the crude product was sufficiently pure for further use. An analysis of a sample recrystallized from ligroin gave the required percentage of halogen.

0.2721 grm. substance gave 0.5556 grm. AgCl + AgBr.

	Calculated for $C_4HCl_2O_2Br$.	Found.
Cl + Br	65.09	64.91

Mucochlorylbromide is very readily soluble in alcohol, ether, chloroform, carbonic disulphide, or benzol; in ligroin it is somewhat more sparingly soluble. From a solution in dilute alcohol it may be obtained by spontaneous evaporation in large transparent plates which melt at 36°. In alcoholic solution it gives with dilute alkalies a deep purple color, which rapidly passes into a wine-red and finally to yellow. With sodic carbonate we have also frequently noticed the formation of a deep green color after the wine-red.

The reduction of the mucochlorylbromide is easily effected by means of stannous chloride and hydrochloric acid. The reaction proceeds slowly in the cold, but may be carried to the end at ordinary temperatures. On warming gently it runs rapidly with the evolution of heat, and in a short time, if the reaction is promoted by vigorous shaking, the mucochlorylbromide completely disappears. On cooling and adding water the dichlorlactone separates in long slender needles, while the mother liquor yields on distillation with steam a small quantity of the same body. The yield amounts to 78 per cent of the weight which could theoretically be obtained from the mucochlorylbromide, or, taking both reactions into account, 70 per cent of the amount which the mucochloric acid employed should give. The substance recrystallized from ligroin gave on analysis the following results: —

I. 0.4362 grm. substance gave 0.4955 grm. CO_2 and 0.0574 grm. H_2O.
II. 0.3097 grm. substance gave 0.5789 grm. AgCl.

	Calculated for $C_4H_2Cl_2O_2$.	Found. I.	Found. II.
C	31.37	30.97	
H	1.31	1.46	
Cl	46.40		46.21

This dichlorcrotonolactone we have also made by the decomposition of trichlorpyromucic acid, and by the action of bromine water upon βγ-dichlorpyromucic acid. Trichlorpyromucic acid appears to be more stable than tribrompyromucic acid. Still it is slowly decomposed with the evolution of carbonic dioxide, when heated to boiling with 50 per cent sulphuric acid, and the dichlorlactone is formed. We have made by this method only a sufficient quantity of material to enable us to identify it with precision. In studying the action of bromine upon βγ-dichlorpyromucic acid we followed the same method that we had employed with the βγ-dibrompyromucic acid, and found that the reaction followed precisely the same course. In this case, however, we proved the presence of mucochlorylbromide among the insoluble products of the reaction only through the characteristic color which was developed upon the addition of sodic carbonate to the alcoholic solution. The dichlorlactone was isolated from the aqueous solution by distillation with steam, as well as by extraction with ether. Its identity was proved by its melting point, and by its conversion into α-phenylamido-β-chlorcrotonolactone melting at 183°.*

αβ-Dichlorcrotonolactone is very readily soluble in benzol or chloroform, readily in alcohol or ether, somewhat more sparingly soluble in carbonic disulphide, and sparingly soluble in cold ligroin, although more freely soluble in hot. It dissolves quite readily in boiling water, and volatilizes freely with steam. The substance crystallizes ordinarily in long silky needles, but on slow evaporation of the ethereal solution it is deposited in clear six-sided plates. It melts at 50–51°, and boils under a pressure of 18 mm. at 114–115° without noticeable decomposition. With aqueous alkalies it behaves like the corresponding bromine compound, and gives a bright yellow solution. Hydroxylamine has no action upon it, and phenylhydrazine removes chlorine without forming any crystalline product. Aniline when added to its solution in dilute alcohol gives the highly crystalline α-phenylamido-β-chlorcrotonolactone. Hydriodic acid gives at 100° the α-iod-β-chlorcrotonolactone.

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* See page 36.

Action of Oxidizing Agents.

α-β-Dichlorcrotonolactone is oxidized with even more difficulty than the corresponding dibromlactone. After boiling for several hours with eight times its weight of concentrated nitric acid (sp. gr. 1.42), a large part of the lactone remained unaltered, and could be recovered by distillation with steam. The aqueous solution was then evaporated to dryness on the water bath, and the crystalline residue treated with small quantities of cold water. Mucochloric acid was then left behind, which after recrystallization from hot water melted at 124–125°. The cold water had taken up a small quantity of a readily soluble acid, which undoubtedly was dichlormaleic acid. Since mucochloric acid yields dichlormaleic acid on oxidation with nitric acid, although it is attacked with more difficulty than mucobromic acid, it did not seem to us worth while to take further steps for its preparation in larger quantity and identification. Bromine dissolved in concentrated hydrochloric acid oxidizes the dichlorlactone, although in this case also long continued boiling is required to complete the reaction.

Action of Aniline.

Aniline readily reacts upon the αβ-dichlorcrotonolactone at ordinary temperatures, and forms the α-phenylamido-β-chlorcrotonolactone. The reaction runs best with a dilute solution in 50 per cent alcohol, and on standing the product separates in broad glistening leaflets, which are more or less highly colored. This color may be removed by recrystallization from glacial acetic acid or from alcohol.

0.1491 grm. substance gave 0.1011 grm. AgCl.

	Calculated for $C_{10}H_8ClNO_2$.	Found.
Cl	16.91	16.76

α-Phenylamido-β-chlorcrotonolactone is quite readily soluble in boiling alcohol, and but sparingly soluble in cold. It also dissolves quite freely in boiling chloroform or benzol, more sparingly in ether or carbonic disulphide, and is almost insoluble in ligroin. It is very sparingly soluble in boiling water, and is deposited in the form of fine needles as the solution cools. From chloroform it crystallizes in clear flat prisms, which melt quite sharply at 183°, although decomposition sets in at a somewhat higher temperature. Toward alkalies it behaves like the corresponding bromine derivative. It dissolves more freely in dilute sodic hydrate on heating than in water, and, if this solution is quickly cooled, it crystallizes out apparently unchanged. On longer heating decomposition ensues with the formation of phenylisocyanide.

Action of Hydriodic Acid.

The action of hydriodic acid upon the αβ-dichlorcrotonolactone we have studied only so far as to prove that α-iod-β-chlorcrotonolactone is formed. This body we have also made directly from mucochlorylbromide by the action of hydriodic acid at 100°. In order to keep up the strength of the hydriodic acid we found it advantageous to add at the same time potassic iodide and red phosphorus. The product was precipitated by the addition of water decolorized with sulphurous acid and recrystallized from alcohol.

0.2015 grm. substance gave 0.3116 grm. AgCl + AgI.

	Calculated for $C_4H_2ClIO_2$.	Found.
Cl + I	66.45	66.36

α-Iod-β-chlorcrotonolactone dissolves very readily in benzol, is freely soluble in ether, but is more sparingly soluble in chloroform or carbonic disulphide. It dissolves easily in hot alcohol, but as this solution cools the greater part separates in long flattened needles which melt at 108–109°. In its behavior toward reagents it closely resembles the bodies of similar constitution already described.

β-CHLORCROTONOLACTONE.

By the action of zinc dust and glacial acetic acid the αβ-dichlorcrotonolactone may be reduced without difficulty to the β-chlorcrotonolactone, but the physical properties of the latter body make its isolation a little more troublesome than that of the corresponding body containing bromine. We dissolved the dichlorcrotonolactone in nearly twice its weight of 80 per cent acetic acid, and slowly added with cooling somewhat more than the theoretical quantity of zinc dust. The reduction was at first attended with the evolution of heat, but afterward became sluggish. After standing over night, the viscous solution, in which some metallic zinc was still suspended, was warmed, filtered, and the clear filtrate diluted with water. As the oil which was then precipitated showed no tendency to crystallize when cooled and scratched, the whole was extracted with ether, the ethereal solution washed with a dilute solution of sodic carbonate, dried with calcic chloride, and the ether removed by distillation. The liquid residue left by the ether was then distilled under diminished pressure. After two distillations the greater part of the product was collected between 128° and 130°, under a pressure of 22 mm., and on cooling this fraction to 10° the larger portion of it solidified. The solid was drained on the pump in a Gooch crucible, and carefully pressed with filter paper. This perfectly dry material was then melted, cooled, and the crystalline solid again pressed, and these operations repeated for a second time without raising perceptibly the melting point. An analysis showed that the body was a chlorcrotonolactone.

0.3071 grm. substance gave 0.3720 grm. AgCl.

	Calculated for $C_4H_3ClO_2$.	Found.
Cl	29.95	29.95

The β-chlorcrotonolactone is very readily soluble in alcohol, ether, chloroform, or benzol; less soluble in carbonic disulphide, and sparingly soluble in ligroin. It may be crystallized most conveniently by strongly cooling the ethereal solution after the addition of ligroin. It crystallizes in well-formed flat prisms, which melt at 25–26°. The boiling point of the pure substance was found to be 124–125° under a pressure of 18 mm. It is quite freely soluble in hot water, and distils slowly with steam. Toward the alkaline hydrates and aniline it behaves like the β-bromcrotonolactone. We have not yet studied its behavior toward bromine or oxidizing agents. Although the βδ-dichlorpyromucic acid is an extremely expensive substance on account of the difficulties which lie in the way of its preparation, and the small yield which can be obtained, its conversion into this same β-chlorcrotonolactone by heating with acids seemed to us of sufficient importance to warrant an experiment in this direction. We therefore heated to boiling 0.7 grm. of the acid with 7 grm. of sulphuric acid of sp. gr. 1.43. Carbonic dioxide was slowly evolved, and the sulphuric acid became strongly colored. After boiling for several hours the solution was cooled, diluted, and extracted with ether. The ethereal extract was then washed with a dilute solution of sodic carbonate, which took up a small amount of the unaltered dichlorpyromucic acid, and dried with calcic chloride. The greater part of the ether was removed by distillation, the residue transferred to a weighing tube and heated to 60–80° *in vacuo*. The liquid residue which remained weighed 0.13 grm., and on cooling to 13° it almost completely solidified. The well pressed crystalline solid remained friable at the temperature of the room (20°) and melted at 25–26°. Recrystallization from a mixture of ether and ligroin failed to raise this melting point. It was thus proved that the β-chlorcrotonolactone had been formed by the decomposition of the βδ-dichlorpyromucic acid.

α-CHLORCROTONOLACTONE.

The α-chlorcrotonolactone melting at 52–53° was prepared several years ago by Hill and L. L. Jackson * through the decomposition of the γδ(χ)-dichlorpyromucic acid. The close relationship between this substance and a body of similar composition containing bromine, which had been discovered by Hill and Sanger,† was recognized at the time, but no attempt was made to establish experimentally this connection. The body containing bromine, which was described by Hill and Sanger, has already been shown to be the α-bromcrotonolactone, and it is easy to establish the identity in structure of the bromine and chlorine derivatives through the reaction with aniline. The α-chlorcrotonolactone when dissolved in dilute alcohol yields with aniline the α-phenylamidocrotonolactone melting at 217–218°, which we have already described as prepared in the same way from the α-bromcrotonolactone.

Since the α-bromcrotonolactone had been made from the βδ-dibrompyromucic acid through the reduction of the brommaleylbromide, which is formed from it by the action of bromine, it seemed to us of interest to prepare the α-chlorcrotonolactone by the same method from the βδ-dichlorpyromucic acid. Pure βδ-dichlorpyromucic acid was suspended in 25 times its weight of cold water, and dissolved by the cautious addition of sodic carbonate. Two molecules of bromine were then added to the feebly alkaline solution, and the whole allowed to stand over night. As the oil which had separated would not crystallize when strongly cooled and scratched, it was taken up with ether, and the residue left on the evaporation of the ether dissolved in 80 per cent acetic acid. Zinc dust was then added to this solution with careful cooling. When the reaction appeared to be complete, the filtered solution was diluted, extracted with ether, the ethereal solution washed with sodic carbonate and distilled. The residue soon crystallized in long slender prisms, which when recrystallized from ligroin melted at 52–53°, and in other respects showed the behavior of the α-chlorcrotonolactone. The βδ-dichlorpyromucic acid, like the corresponding acid containing bromine, may, therefore, be made to yield either the α- or the β-chlorcrotonolactone. While we had no doubt that the γδ-dichlorpyromucic acid would show an essentially different behavior, and would yield, when treated in this way, the same α-chlorcrotonolactone which it gives when heated with acids, we thought it worth while to establish the fact by experiment. The γδ-dichlorpyromucic acid was therefore treated with bromine in a feebly alkaline solution, and the oil, which was thus formed, was then reduced with zinc dust and glacial acetic acid. It was easy to isolate, as before, the α-chlorcrotonolactone melting at 52–53° with its characteristic properties.

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* These Proceedings, XXIV. 333.

† Ibid., XXI. 158.

α-PHENOXY-β-BROMCROTONOLACTONE.

Many years ago Hill and Stevens * prepared from mucobromic acid, by the action of potassic phenylate, a derivative of mucobromic acid, in which one atom of bromine was replaced by the phenoxy group, and to which they gave the name mucophenoxybromic acid.† They showed that this acid had the same general structure as the mucobromic acid, in that it could be converted by oxidation into a phenoxybrommaleic acid, and that it yielded on decomposition with alkalies a phenoxybromacrylic acid. The stability of the latter acid in alkaline solution led them to the conclusion that it contained the phenoxy group in the α position. Although none of the substituted crotonolactones which we had studied could directly be converted into the salts of the oxy-acids, it seemed to us probable that the corresponding bodies containing the phenoxy group would react more smoothly. As the preliminary experiments which we made on the action of sodic or potassic phenylate upon the dibromcrotonolactone gave us little hope that the desired bodies could be made in this way, we turned to the mucophenoxybromic acid, and found that the α-phe-

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* These Proceedings, XIX. 262.

† Beilstein in the second edition of his "Handbuch der organischen Chemie" (II. 429) has seen fit to change this name to phenoxymucobromic acid. It is quite possible that we might have selected a better name for our new body, but it certainly would be difficult to find one more misleading than that which Beilstein has chosen to give it. Whatever else it may be, it certainly is *not* a phenoxymucobromic acid. H. B. H.

noxy-β-bromcrotonolactone could easily be made by the reduction of its bromanhydride.

The mucophenoxybromylbromide was not described by Hill and Stevens, but we found that it could be made without difficulty, in nearly theoretical quantity, by the action of phosphorous tribromide. We used but little more than one molecule of the tribromide to three molecules of the acid, and heated at 100°. When the liquid product became turbid with the separation of phosphorous acid, we added cold water with constant shaking. The bromide immediately separated in a granular form, and could be recrystallized from small quantities of alcohol. It formed fine concentrically grouped needles, which melted at 95–96°.

0.2363 grm. substance gave 0.2656 grm. AgBr.

	Calculated for $C_4H(OC_6H_5)Br_2O_2$	Found.
Br	47.90	47.82

Mucophenoxybromylbromide is readily soluble in ether, chloroform, or benzol, readily soluble in hot alcohol, more sparingly in cold, and sparingly soluble in ligroin. With alkalies in alcoholic solution it gives a yellow color. The reduction of this body to the corresponding lactone is slowly but completely effected by stannous chloride and hydrochloric acid at ordinary temperatures, if a little alcohol be added at the same time to facilitate solution. We have found it more convenient, however, to use zinc dust and acetic acid. Since the lactone is almost insoluble in dilute acetic acid, and an excess of zinc dust apparently does no harm, we suspended the bromide in twice its weight of glacial acetic acid (99.5 per cent), and slowly added with careful cooling an excess of zinc dust. After standing for several hours, the reduction is complete, and the addition of water to the filtered solution throws down a beautifully crystalline substance, which may be recrystallized from alcohol. The product thus obtained proved on analysis to have the composition of a phenoxybromcrotonolactone. The weight of the lactone as precipitated by water was 80 per cent of the theoretical amount.

I. 0.3929 grm. substance gave 0.6796 grm. CO_2 and 0.1008 grm. H_2O.
II. 0.1906 grm. substance gave 0.1410 grm. AgBr.

	Calculated for $C_4H_2(OC_6H_5)BrO_2$.	Found. I.	Found. II.
C	47.07	47.18	
H	2.75	2.85	
Br	31.37		31.48

The α-phenoxy-β-bromcrotonolactone is readily soluble in ether, chloroform, benzol, glacial acetic acid, or in hot alcohol, and but sparingly soluble in cold alcohol, or in ligroin. It crystallizes in six-sided plates which melt at 72°. It dissolves slightly in boiling water, and volatilizes slowly with steam. In alcoholic solution it is not attacked by aniline at ordinary temperatures. With aqueous alkalies it is slowly carried into solution, on heating, with the formation of the corresponding salts of the oxy-acid.

α-Phenoxy-β-brom-γ-oxycrotonic Acid. If the α-phenoxy-β-bromcrotonolactone is dissolved in a hot solution of potassic hydrate, and after thorough cooling a slight excess of hydrochloric acid is added, the solution soon becomes filled with colorless pearly scales of the phenoxybromoxycrotonic acid. For analysis the substance was merely washed well with cold water, and dried over sulphuric acid.

I. 0.2782 grm. substance gave 0.4484 grm. CO_2 and 0.0857 grm. H_2O.
II. 0.1588 grm. substance gave 0.1092 grm. AgBr.

	Calculated for $C_4H_4(OC_6H_5)BrO_3$.	Found. I.	Found. II.
C	43.95	43.96	
H	3.30	3.08	
Br	29.30		29.25

The α-phenoxy-β-brom-γ-oxycrotonic acid is readily soluble in alcohol or ether, quite readily soluble in hot chloroform or benzol, and almost insoluble in ligroin. From chloroform it crystallizes in brilliant flat rectangularly terminated prisms. It is very sparingly soluble in cold water, and when warmed it dissolves somewhat more freely, but the solution immediately grows turbid with the formation of the still more sparingly soluble lactone. The identity of the phenoxybromcrotonolactone formed in this way was established by analysis.

0.2696 grm. substance gave 0.2007 grm. AgBr.

	Calculated for $C_4H_2(OC_6H_5)BrO_2$.	Found.
Br	31.37	31.66

The melting point of the acid cannot be determined with precision, since it is converted into the lactone by heat, but under ordinary conditions it is found to be about 98°. The loss of weight which we observed on melting the acid by short exposure to a temperature of 110°, and allowing the fused mass to stand over sulphuric acid, corresponded to a little more than one molecule of water.

0.6318 grm. substance lost 0.0450 grm. H_2O.

	Calculated for $C_4H_4(OC_6H_5)BrO_3$.	Found.
H_2O	6.59	7.12

Baric α-phenoxy-β-brom-γ-oxycrotonate, $Ba(C_4H_3(OC_6H_5)BrO_3)_2 . 3\,H_2O$. — The barium salt is readily soluble even in cold water, and crystallizes in flat prisms with rectangular terminations. It apparently contains three molecules of water, almost the whole of which it readily loses over sulphuric acid.

0.5891 grm. air-dried salt lost over sulphuric acid 0.0430 grm. H_2O, and at 100° it lost 0.0052 grm. H_2O in addition.

	Calculated for $Ba(C_4H_3(OC_6H_5)BrO_3)_2 . 3\,H_2O$.	Found.
H_2O	7.35	8.18

0.4939 grm. anhydrous salt gave 0.1677 grm. $BaSO_4$.

	Calculated for $Ba(C_4H_3(OC_6H_5)BrO_3)_2$.	Found.
Ba	20.11	19.97

The anhydrous salt dissolves without difficulty in strong alcohol, but in a few moments the solution turns solid with the separation of finely felted needles of a salt containing alcohol of crystallization. The same salt may also be obtained by dissolving the hydrous salt in hot alcohol. We have been unable to obtain satisfactory determinations of the amount of alcohol which is thus taken up, since the salt effloresces very rapidly on exposure to the air, and loses the last part of its alcohol with great difficulty.

α-PHENOXY-β-CHLORCROTONOLACTONE.

It seemed to us desirable to confirm the results which we had obtained with the phenoxybromcrotonolactone by preparing also the corresponding bodies containing chlorine. Hill and Stevens had made no experiments as to the action of potassic phenylate upon mucochloric acid, but we found that mucophenoxychloric acid could readily be made in this way. As we were interested only in the preparation of the phenoxychlorcrotonolactone, Mr. H. P. Nash undertook a more careful study of this acid, and will present his results in a separate paper. From the mucophenoxychloric acid we prepared without difficulty the corresponding bromanhydride by the action of phosphorous tribromide. The reaction ran smoothly, and gave us, as in the previous cases, which we have described more in detail, about 90 per cent of the theoretical yield. The body was readily soluble in ether, chloroform, benzol, or glacial acetic acid. It was very readily soluble in hot alcohol, more sparingly in cold, very sparingly soluble in cold ligroin, though more easily soluble in hot. When recrystallized from small quantities of alcohol or from ligroin, it was obtained in radiating needles which melted at 89–90°.

0.2320 grm. substance gave 0.2631 grm. AgCl + AgBr.

	Calculated for $C_4H(OC_6H_5)ClO_2Br$.	Found.
Cl + Br	39.89	39.53

In the reduction of the mucophenoxychlorylbromide to the corresponding lactone we followed the method which had already proved convenient with the mucophenoxybromylbromide. Zinc dust was slowly added with careful cooling to the bromide dissolved in glacial acetic acid. When the reduction was complete, the filtered solution was diluted with water, and the crystalline body which was thus thrown down was recrystallized from a small amount of alcohol. The lactone which was precipitated by water amounted to 76 per cent of the theoretical yield.

I. 0.3243 grm. substance gave 0.6765 grm. CO_2 and 0.0995 grm. H_2O.
II. 0.2256 grm. substance gave 0.1541 grm. AgCl.

	Calculated for $C_4H_2(OC_6H_5)ClO_2$.	Found. I.	II.
C	57.02	56.89	
H	3.33	3.40	
Cl	16.87		16.89

The α-phenoxy-β-chlorcrotonolactone is readily soluble in ether, chloroform, benzol, carbonic disulphide, and in hot alcohol or ligroin, although but sparingly soluble in these solvents when cold, and almost insoluble in water. From alcohol it crystallizes in six-sided plates, or flattened prisms, which melt at 67–68°. In alcoholic solution it is not affected by aniline at ordinary temperatures. When heated with aqueous alkalies it is gradually carried into solution with the formation of the salt of the corresponding oxy-acid.

α-Phenoxy-β-chlor-γ-oxycrotonic Acid, $C_4H_4(OC_6H_5)ClO_3$. — If the α-phenoxy-β-chlorcrotonolactone is dissolved in a moderately dilute solution of potassic hydrate by the aid of heat, and to the well cooled solution a slight excess of hydrochloric acid is added, the phenoxychloroxycrotonic acid separates almost immediately in colorless pearly scales. The crystals were removed by filtration, thoroughly washed with cold water and dried over sulphuric acid. The substance was then analyzed without further purification.

I. 0.4291 grm. substance gave 0.8242 grm. CO_2 and 0.1541 grm. H_2O.
II. 0.2160 grm. substance gave 0.1342 grm. AgCl.

	Calculated for $C_4H_4(OC_6H_5)ClO_3$.	Found. I.	Found. II.
C	52.51	52.37	
H	3.94	3.99	
Cl	15.52		15.36

α-Phenoxy-β-chlor-γ-oxycrotonic acid crystallizes in flat rectangularly truncated prisms which melt at about 76°, but the melting point varies with the rapidity of the heating. It is very soluble in alcohol or ether, quite readily soluble in chloroform or benzol, less soluble in carbonic disulphide or ligroin, and sparingly soluble in water. On heating with water it behaves like the compound containing bromine, which has already been described, and is rapidly converted into the lactone. This conversion is immediately effected when the acid is heated to its melting point. The acid was melted by short exposure to a temperature of 110°, and the fused mass thoroughly dried over sulphuric acid. The loss in weight corresponded almost exactly to that required by one molecule of water.

0.4068 grm. substance lost 0.0333 grm. H_2O.

	Calculated for $C_4H_4(OC_6H_5)ClO_3$.	Found.
H_2O	7.88	8.11

The acid may also be converted into the lactone by longer continued heating at a temperature below its melting point, and this change seems to take place slowly even at ordinary temperatures. After the lapse of many weeks a combustion of the material which had previously given us the proper percentage of chlorine showed that the acid had in part been converted into the lactone.

0.2004 grm. substance gave 0.4018 grm. CO_2 and 0.0676 grm. H_2O.

	Calculated for $C_4H_4(OC_6H_5)ClO_3$.	Calculated for $C_4H_2(OC_6H_5)ClO_2$.	Found.
C	52.51	57.02	54.69
H	3.94	3.33	3.75

Baric α-phenoxy-β-chlor-γ-oxycrotonate, $Ba(C_4H_3(OC_6H_5)ClO_3)_2 \cdot 3\,H_2O$. — The barium salt of the acid is very soluble even in cold water, and crystallizes in long colorless prisms. The air-dried salt contains three molecules of water, all of which it loses over sulphuric acid.

0.5906 grm. air-dried salt lost over sulphuric acid 0.0492 grm. H_2O, and when heated at 100° it lost in addition 0.0002 grm. H_2O.

	Calculated for $Ba(C_4H_3(OC_6H_5)ClO_3)_2 . 3 H_2O$.	Found.
H_2O	8.36	8.36

0.4814 grm. anhydrous salt gave 0.1869 $BaSO_4$.

	Calculated for $Ba(C_4H_3(OC_6H_5)ClO_3)_2$.	Found.
Ba	23.19	22.82

This salt behaves toward alcohol precisely like the baric phenoxybromoxycrotonate, and forms the same finely felted needles.

MUCOBROMIC ACID.

It was shown many years ago by Hill and O. R. Jackson,* that mucobromic acid could be converted into dibrommaleic acid by oxidation with argentic oxide. When their investigation was completed (1880), it was already known that phenylhydrazine reacted upon certain aldehydes, but experimental evidence as to the generality of the reaction had not accumulated, and the importance of this body as a reagent for aldehydes and ketones was not urged by E. Fischer † until several years later. The characteristic behavior of hydroxylamine with aldehydes and ketones was also not discovered by V. Meyer ‡ until two years later. Since the facts which we have described in the preceding pages, tended to show that mucobromic acid was an oxylactone and not an aldehyde acid, it was evidently necessary for us to study its behavior toward phenylhydrazine and hydroxylamine. Phenylhydrazine has unfortunately given us no bodies the physical properties of which invited further investigation, but with hydroxylamine we have been more successful. We have also studied the action of ammonia upon ethylmucobromate, and found that mucobromamide is thus formed.

Mucobromoxime, $C_4H_3Br_2NO_3$. — Hydroxylamine acts with great ease upon mucobromic acid, but we have been able to isolate the oxime only when the reaction takes place in an alkaline aqueous solution. The decomposition is almost instantaneous, so that after the lapse of a few minutes the solution deposits upon acidification the oxime in a granular condition. This granular precipitate was at once removed by filtration, well washed with cold water, and dried over sulphuric acid.

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* These Proceedings, XVI. 186.

† Berichte d. deutsch. chem. Gesellsch., XVII. 572.

‡ Ibid., XV. 1165, 1324, 1527, 2778, 2783; XVI. 822.

I. 0.2397 grm. substance gave 0.1575 grm. CO_2 and 0.0415 grm. H_2O.
II. 0.3133 grm. substance gave 0.2043 grm. CO_2.*
III. 0.2524 grm. substance gave 0.3481 grm. AgBr.

	Calculated for $C_4H_3Br_2NO_3$.	Found. I.	II.	III.
C	17.58	17.92	17.58	
H	1.10	1.92		
Br	58.61			58.68

This oxime is readily soluble in alcohol or ether, and but sparingly soluble in chloroform or benzol. In cold water it is also sparingly soluble, but dissolves readily on boiling. If the hot solution is immediately cooled the oxime anhydride separates, but otherwise the acid ammonium salt of dibrommaleic acid is formed, and remains in solution. The oxime has no definite melting point, but is evidently converted into the anhydride by heat. It usually melts, at least in part, at about 90°, but this point varies with the rate of heating.

Mucobromoxime Anhydride, $C_4HBr_2NO_2$. — Under ordinary conditions the only product formed by the action of hydroxylamine or its hydrochlorate upon mucobromic acid is the anhydride of the oxime. Moreover, if in the preparation of the oxime by the method just described the precipitated substance is allowed to stand for several hours in the mother liquor, the anhydride is formed. The material used in Analysis III. was made by the action of hydroxylamine hydrochlorate upon a solution of mucobromic acid in strong methyl alcohol; for the other determinations, preparations were employed which had been made in a solution in dilute methyl alcohol with the addition of one equivalent of sodic carbonate. In each case the reaction ran rapidly at ordinary temperatures, and the anhydride which separated was washed well with cold water, and dried over sulphuric acid.

I. 0.2927 grm. substance gave 0.4334 grm. AgBr.
II. 0.2393 grm. substance gave 0.3547 grm. AgBr.
III. 0.1801 grm. substance gave 0.2670 grm. AgBr.
IV. 0.2014 grm. substance gave 10.0 c.c. of moist nitrogen at 19° and under a pressure of 753 mm.
V. 0.3127 grm. substance gave 14.5 c.c. of moist nitrogen at 15° and under a pressure of 764 mm.

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* The hydrogen in this combustion was lost.

	Calculated for $C_4HBr_2NO_2$.	Found.				
		I.	II.	III.	IV.	V.
Br	62.75	63.00	63.07	63.08		
N	5.49				5.65	5.45

Mucobromoxime anhydride dissolves quite readily in alcohol, chloroform, or benzol; with somewhat more difficulty in ether or carbonic disulphide; and is almost insoluble in ligroin. It crystallizes in dendritic needles, which melt at about 117–118°, but this melting point varies with the conditions under which it is taken. If the melted substance be heated to a higher temperature, it solidifies again below 140° and melts then for a second time at 218°. This behavior is due to the conversion of the anhydride into the isomeric dibrommaleinimide, which melts, according to Ciamician and Silber,* at 225°. If this isomerization is brought about by plunging the tube containing a considerable quantity of the substance into a bath heated to 115°, the reaction is violent, but also attended with decomposition. The anhydride is sparingly soluble in cold water, although more readily in hot. If the hot solution is quickly cooled the anhydride separates, but on prolonged heating it is completely converted into the acid ammonium salt of dibrommaleic acid. This acid was identified through its characteristic barium salt and the melting point (114°) of its anhydride.

Methyl Ester of Mucobromoxime, $C_4H_2Br_2NO_3CH_3$. — Although hydroxylamine hydrochlorate reacts at ordinary temperatures upon mucobromic acid when dissolved in strong methyl alcohol, and forms the mucobromoxime anhydride, if the reaction takes place at the boiling point of the methyl alcohol the methyl ester of the oxime results. The same body is also formed when the anhydride is boiled for a short time with methyl alcohol. For its preparation we found it advantageous to dissolve mucobromic acid in rather less than twice its weight of methyl alcohol, to add a little more than one molecule of hydroxylamine hydrochlorate dissolved in the smallest possible quantity of water, and to boil with reverse cooler for twenty minutes. On cooling, the methyl ester then separated in abundance.

I. 0.4336 grm. substance gave 0.3370 grm. CO_2 and 0.0915 grm. H_2O.
II. 0.2946 grm. substance gave 0.3899 grm. AgBr.

	Calculated for $C_4H_2Br_2NO_3CH_3$.	Found.	
		I.	II.
C	20.90	21.19	
H	1.74	2.34	
Br	55.75		56.31

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* Berichte d. deutsch. chem. Gesellsch., XVII. 556.

The methyl ester of mucobromoxime is readily soluble in alcohol, somewhat more sparingly soluble in ether, and very sparingly soluble in chloroform or benzol. It is also very sparingly soluble in cold water, but dissolves freely on heating, and, if the solution is quickly cooled, it separates in finely felted needles. On continued boiling it is converted into dibrommaleinimide, and the same change is also effected by longer boiling with methyl alcohol. The ester melts at 146–147°, and at a slightly higher temperature solidifies with the formation of dibrommaleinimide, which again melts at 218°. The conversion of the ester into the imide may also be brought about by dissolving it in sodic carbonate, and acidifying the solution with hydrochloric acid. The imide melting at 218° is thus thrown down. If the alkaline hydrates are used to dissolve the ester, great care must be used to avoid an excess. This same ester may also be made by the action of hydroxylamine hydrochlorate upon methyl mucobromate dissolved in methyl alcohol. We found, however, that substantially no reaction took place when a ten per cent solution of the ester stood at ordinary temperatures for several days, either with free hydroxylamine or with its hydrochlorate. The solutions when cooled with ice and salt deposited no crystals in material amount, and on dilution with water the original ester was recovered essentially unchanged. With free hydroxylamine there seemed to be but slow action even on boiling; but on boiling the solution containing the hydrochlorate for half an hour, a copious separation of the methyl ester of the mucobromoxime melting at 146–147° was obtained on cooling. On boiling for a longer time this ester was almost wholly converted into dibrommaleinimide melting at 218°.

Although it had been found that the methyl ester of mucobromoxime could not be dissolved in alkalies without the formation of dibrommaleinimide, it seemed to us possible that we might form a silver salt. On the addition of an alcoholic solution of argentic nitrate to an alcoholic solution of the ester, no salt was precipitated, and no crystals separated on standing. Alcoholic ammonia was then cautiously added, and the first drop brought down a heavy yellow pulverulent precipitate, although the addition of two molecules was necessary to complete the precipitation. The salt was insoluble in water or alcohol, and was not affected by an excess of ammonia. On analysis it proved to be an ammonio-silver salt of dibrommaleinimide, corresponding to the ammonio-silver compound of dichlormaleinimide described by Ciamician and Silber.* Nitric acid decomposed it with the liberation of dibrommaleinimide.

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* Berichte d. deutsch. chem. Gesellsch., XVI. 2394.

I. 0.2916 grm. substance gave with HBr 0.1410 grm. AgBr.

II. 0.2384 grm. substance gave with HNO_3 and $AgNO_3$ 0.2347 grm. AgBr.

III. 0.3502 grm. substance gave 22.2 c.c. of moist nitrogen at 19° and under a pressure of 754 mm.

	Calculated for $C_4Br_2NO_2AgNH_3$.	Found. I.	II.	III.
Ag	28.51	28.37		
Br	42.23		41.89	
N	7.39			7.37

A salt which closely resembles that which we have just described is precipitated when an alcoholic solution of argentic nitrate is added to an alcoholic solution of dibrommaleinimide. It can contain no ammonia, however, and is the silver salt of the imide.

0.3153 grm. substance gave 10.7 c.c. of moist nitrogen at 17° and under a pressure of 777 mm.

	Calculated for $C_4Br_2NO_2Ag$	Found.
N	3.87	4.02

The strongly acid filtrate from this salt gave with alcoholic ammonia an ammonio-silver salt identical with that prepared from the methyl ester of mucobromoxime.

0.3553 grm. substance gave 21.9 c.c. of moist nitrogen at 17° and under a pressure of 775 mm.

	Calculated for $C_4Br_2NO_2AgNH_3$.	Found.
N	7.39	7.30

In the preparation of the mucobromoxime methyl ester directly from mucobromic acid, there is also formed an oil, which, although somewhat soluble in water, is precipitated by the addition of water to the methyl-alcoholic mother liquors. We have not obtained it in a condition fit for analysis, but as it is readily decomposed by water with the formation of dibrommaleic acid it is doubtless an acid ester of this acid.

Mucobromamide, $C_4HBr_2O_2NH_2$ — When ammonia gas is passed into a solution of ethyl mucobromate in dry ether, reaction immediately takes place, and mucobromamide separates. This body may also be prepared by the action of alcoholic ammonia upon an alcoholic solution of the ester at ordinary temperatures, but the product so obtained is dark colored and must be treated with bone-black in acid solution, and recrystallized from hot water. We have also prepared mucobromamide by the action of ammonia upon mucobromylbromide dissolved in anhydrous ether.

I. 0.3496 grm. substance gave 0.2426 grm. CO_2 and 0.0555 grm. H_2O.
II. 0.3640 grm. substance gave 0.5342 grm. AgBr.
III. 0.2033 grm. substance gave 10.7 c.c. of moist nitrogen at 18°.5, and under a pressure of 769 mm.

	Calculated for $C_4HBrO_2NH_2$	Found. I.	II.	III.
C	18.68	18.92		
H	1.20	1.77		
Br	62.26		62.44	
N	5.45			6.13

Mucobromamide is nearly insoluble in ether, chloroform, or benzol, and is readily soluble in hot, more sparingly in cold alcohol. It dissolves very readily in hot water, and separates almost completely as the solution cools in colorless dendritic needles, which melt with decomposition at about 170°. Slight impurities apparently lower very greatly this point of melting and decomposition. Alkaline hydrates added in excess carry it completely into solution in the cold without the formation of any color, but, if an excess be not added, the solution rapidly turns brown or black. From the colorless solution the immediate addition of acid reprecipitates the amide unchanged. It may be recrystallized from hot concentrated hydrochloric acid, or from dilute sulphuric acid, but after long heating with concentrated hydrochloric acid, or boiling for a shorter time with distillable hydrobromic acid, mucobromic acid melting at 120° is formed. The amide dissolved readily in fuming nitric acid, and on long standing this solution deposited well formed crystals of dibrommaleinimide melting at 218°. Dilute solutions of chromic acid with an excess of sulphuric acid effected little change even on long boiling, but in concentrated solution oxidation took place and dibrommaleinimide was formed. This same body was also formed when the amide was heated with dry bromine at 100°.

We made many attempts to make from the mucobromamide by the action of hydroxylamine, phenylhydrazine, or aniline, the corresponding derivatives, but in no case were we successful. Either the amide was recovered unchanged, or in a few cases in working with the free bases at higher temperatures a deeper decomposition ensued.

Mucochloric Acid.

Toward hydroxylamine mucochloric acid behaves in essentially the same way as mucobromic acid, although we have been unable as yet to prepare the anhydride of the oxime, the body which was most readily formed from mucobromic acid. The methyl ester of mucochloric acid when treated with ammonia gave mucochloramide without difficulty.

Mucochloroxime, $C_4H_3Cl_2NO_3 \cdot \frac{1}{2} H_2O$. — Mucochloric acid was dissolved in a small amount of methyl alcohol, and one equivalent each of hydroxylamine and sodic carbonate dissolved in a little water were added. After the lapse of a few minutes the solution was acidified with hydrochloric acid and the oxime immediately separated. Analyses of the air-dried material (III.) or of the substance dried over sulphuric acid (I. and II.) showed that in each case one half-molecule of water was retained. Since dichlormaleinimide was quickly formed at temperatures below 100°, no attempt was made to dehydrate the substance by heat.

I. 0.2220 grm. substance gave 0.2014 grm. CO_2 and 0.0471 grm. H_2O.
II. 0.2008 grm. substance gave 0.2992 grm. AgCl.
III. 0.1927 grm. substance gave 0.2851 grm. AgCl.

	Calculated for $C_4H_3Cl_2NO_3 \cdot \frac{1}{2} H_2O$.		Found.	
		I.	II.	III.
C	24.87	24.79		
H	2.07	2.36		
Cl	36.79		36.58	36.85

Mucochloroxime crystallizes in slender felted needles, which are readily soluble in alcohol or ether, and but sparingly soluble in cold water. It dissolves readily in hot water, and if the solution is quickly cooled, it separates apparently unchanged, but on heating for a short time with water it is converted into the acid ammonium salt of dichlormaleic acid. The identity of the acid extracted by ether from the acidified solution was established by the melting point of its anhydride (119°). The melting point of the oxime cannot be determined with precision, but it lies in the neighborhood of 90°. The melted oxime passes into the dichlormaleinimide which solidifies and again melts at 175–177°.

Methylester of Mucochloroxime, $C_4H_2Cl_2NO_3CH_3$. — The methyl ester of mucochloroxime is formed when a cold solution of the oxime in methyl alcohol is allowed to stand for twenty-four hours, or when mucochloric acid is dissolved in its own weight of methyl alcohol, hydroxylamine hydrochlorate dissolved in a little water added in somewhat more than equivalent quantity, and the whole allowed to stand at ordinary temperatures. If the solution is boiled even for a short time the chief product is dichlormaleinimide. The ester may also be made by the action of hydroxylamine hydrochlorate upon methyl mucochlorate, provided the solution in methyl alcohol be allowed to stand for several days.

0.1676 grm. substance gave 0.2437 grm. AgCl.

	Calculated for $C_4H_2Cl_2NO_3CH_3$.	Found.
Cl	35.86	35.94

The methyl ester of the mucochloroxime crystallizes in flattened needles, the melting point of which varies with the mode of heating. When introduced into a heated bath the substance melts promptly when the temperature is held at 135°. At higher temperatures the melted ester again solidifies, with the formation of dichlormaleinimide, which in its turn melts at 173–174°. The ester is readily soluble in alcohol, ether, or chloroform, and but sparingly soluble in benzol or carbonic disulphide. It is also sparingly soluble in cold water, but dissolves more readily in hot water, and, if the solution is quickly cooled, it separates in long felted needles. On longer heating with water it is converted into dichlormaleinimide. The ester may also be converted into the imide by dissolving it in a solution of sodic carbonate, and acidifying with hydrochloric acid, provided the solution is cold, and moderately concentrated, and the acid is immediately added.

Mucochloramide, $C_4HCl_2O_2NH_2$. — Mucochloramide is readily formed when ammonia gas is passed into a solution of methyl mucochlorate in dry ether. The hard dark-colored mass which separates is ground up in a mortar with small quantities of cold water. The greater part of the coloring matter is thus removed, and the residue may then be recrystallized from boiling water.

0.2115 grm. substance gave 0.3606 grm. AgCl.

	Calculated for $C_4HCl_2O_2NH_2$.	Found.
Cl	42.27	42.15

Mucochloramide is readily soluble in alcohol, sparingly soluble in ether, and almost insoluble in chloroform. It dissolves readily in hot water, and as the solution cools the greater part is deposited in the form of small oblique prisms, which melt at about 166°. Like mucobromamide it dissolves readily in solutions of the alkaline hydrates, and is reprecipitated unchanged if the alkaline solution is immediately acidified. On boiling for some time with concentrated hydrochloric acid, it is converted into mucochloric acid, as was shown by the melting point, 124°.

MUCOPHENOXYBROMIC ACID.

Mucophenoxybromoxime, $C_4H_3(OC_6H_5)BrNO_3$. — We have found that hydroxylamine readily reacts upon mucophenoxybromic acid, and that the corresponding oxime is formed both in alkaline and acid solution. It may conveniently be prepared by adding to a solution of the acid in 20 times its weight of 50 per cent methyl alcohol the equivalent amount of hydroxylamine hydrochlorate. After standing for a short time at ordinary temperatures the oxime begins to separate in beautiful clusters of long needles, and in a few hours the reaction is completed.

0.2717 grm. substance gave 0.1791 grm. AgBr.

	Calculated for $C_4H_3(OC_6H_5)BrNO_3$.	Found.
Br	27.97	28.04

Mucophenoxybromoxime is readily soluble in alcohol or ether, and insoluble in chloroform or benzol. It is almost insoluble in cold water, dissolves but sparingly in boiling, and separates apparently unchanged if the solution is quickly cooled. On long boiling it is decomposed, and the solution then contains ammonia and phenoxybrommaleic acid. The solution was acidified with hydrochloric acid, extracted with ether, and the acid removed from the ethereal solution with sodic carbonate. The alkaline solution then gave on acidification small clustered needles, which melted at 104–105° when rapidly heated. On sublimation a crystalline body was obtained which melted at 91°. According to Hill and Stevens, phenoxybrommaleic acid, when quickly heated, melts at 104–105°, and we found that their acid when sublimed yielded the anhydride melting at 91°. The oxime shows great variation in melting point (120–135°), according to the mode of heating, and we have not yet been able to show that it is converted into the phenoxybrommaleinimide by heat. The melted body did not solidify on further heating, nor did it crystallize on cooling.

MUCOPHENOXYCHLORIC ACID.

Mucophenoxychloroxime, $C_4H_3(OC_6H_5)ClNO_3$. — This body is formed by the action of either hydroxylamine, or its hydrochlorate, at ordinary temperatures upon mucophenoxychloric acid. As in previous cases we used diluted methyl alcohol as a solvent. The oxime began to crystallize almost immediately, and the separation was in a short time complete. The material used in Analysis I. was prepared by the action of the free base; that in Analysis II. with the hydrochlorate.

I. 0.2025 grm. substance gave 0.1202 grm. AgCl.
II. 0.2137 grm. substance gave 0.1294 grm. AgCl.

	Calculated for $C_4H_3(OC_6H_5)ClNO_3$.	Found.	
		I.	II.
Cl	14.70	14.68	14.97

Mucophenoxychloroxime crystallizes in clustered needles, which melt at 112–125°, according to the mode of heating. It dissolves readily in alcohol or ether, but is insoluble in chloroform or benzol. It is almost insoluble in cold water, dissolves somewhat more freely on heating, and crystallizes out unchanged if the solution is quickly cooled. On longer boiling it is decomposed, and the solution then contains the acid ammonium salt of an acid which we have not yet further examined.

II.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF BARIUM.

SECOND PAPER: THE ANALYSIS OF BARIC CHLORIDE.

By Theodore William Richards.

Presented May 10, 1893.

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Introduction.

During the time occupied by the recent investigation of baric bromide,* similar analyses of baric chloride were being made. The problem involved was far more complicated than the one already published, because of the solubility of argentic chloride in water; hence the present paper, which might well have come first, was necessarily postponed. The results of the continued investigation confirmed the high value of the atomic weight of barium, 137.43, obtained from the results of the investigation of baric bromide.

The balance and weights, and all the precautions relative to the weighings, have been already described in detail.† The remarks made before about the constancy of the weights, and the various comparisons with the Washington standard, naturally apply with equal force to the present work. At the close of the two years' investigation the weights were again compared, and were found to have remained surprisingly constant in relative value.

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* These Proceedings, XXVIII. 1. Zeitschr. Anorg. Chem., III. 441; IV. 160.

† Ibid., XXVI. 242; also XXVIII. 5.

The following atomic weights of various elements entering into the present research will be assumed throughout the paper:—

Oxygen	= 16.000	Hydrogen	= 1.0075
Bromine	= 79.955	Silver	= 107.930
Chlorine	= 35.456	Sulphur	= 32.065

Properties of Baric Chloride.

The properties of baric chloride are so familiar as to need little further description.* The colorless flat tables of the rhombic system contain, as is very well known, two molecules of water together with the usual slight excess. Half of this water is given off at 60–65°,† and the rest at somewhat higher temperatures. All the water is regained at ordinary temperatures in ordinary moist air. According to Filhol ‡ the crystals possess a specific gravity of 2.66, while according to Joule and Playfair,‖ Schiff,§ and Schroeder ¶ they possess a specific gravity of about 3.05. This great discrepancy is too serious to neglect, hence a redetermination was made.

The apparatus for the determination of the specific gravity was similar to that already described,** and toluol was again used as the liquid to be displaced. 5.701 grams (in air) of powdered crystallized baric chloride were found to displace 1.5864 grams of toluol at 24°, or 1.8408 grams of water at 4°. Hence the specific gravity sought is 3.097. The reason for at least a part of the discrepancy is undoubtedly to be found in the enclosure of varying amounts of mother liquor in the crystals.

The specific gravity of anhydrous baric chloride has been much more definitely determined. According to Quincke,†† the value of this constant is 3.851 at 0°; according to Favre and Volson,‡‡ it is 3.844 at 17°; and according to Schroeder,§§ it is 3.879 at 4°. Although without doubt the mean of these values would have served the present purpose, a new determination was made, as much to check the previ-

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[*] See Graham Otto (Michaelis), III. 658; also Watt's Dictionary (Muir), I. 441, etc.

[†] Lescœur, Compt. Rend., CIV. 1511.

[‡] Graham Otto (Michaelis), *loc. cit.*

[‖] Chem. Soc. Mem., II. 401; III. 57, 199.

[§] Annalen, CVIII. 21.

[¶] Jahresbericht 1879, p. 31.

[**] These Proceedings, XXVIII. 14.

[††] Graham Otto (Michaelis), III. 659.

[‡‡] Ibid.

[§§] Berichte d. deutsch. c. Gesell. 1878, 2131.

ous determinations in the present research as to serve for the basis of reduction to vacuum.

4.8620 grams (in air) of baric chloride which had been dried to constant weight at 220° were found to occupy the same volume at 24° as 1.2608 grams of water reduced to 4°. Hence the specific gravity of baric chloride under these conditions is 3.856, a value which agrees essentially with those given above.

Here, as in the case of baric bromide, the question whether the water of crystallization is absolutely expelled at a red heat is one of the greatest importance. All early experiments have assumed that this is the case, without attempting to disprove the contrary assumption. The first stumbling block in the way of the careful investigation of the problem is the decomposition of baric chloride in the air at high temperatures. Marignac's statement that the salt may be ignited at a dull red heat without the loss of a trace of chlorine * has not been confirmed by the present experience. As a matter of fact, baric chloride loses almost as much halogen as the bromide, upon gentle ignition in the air.† Hence in order to determine the true weight of baric chloride present in all those cases where the salt was ignited in this way, it was necessary to determine the amount of baric hydroxide and baric carbonate existing in the solution of the ignited salt. Pure boiled water which had been prepared solely in platinum was used for making this solution, and phenol phthaleïn and methyl orange were used as indicators. Of course, the loss of 0.00355 gram of chlorine would correspond to a correction of +0.00055 gram to the weight of the baric chloride if the alkaline earth were in the form of carbonate, +0.00185 gram if it were in the form of hydroxide, or +0.00275 gram if it were in the form of oxide. Since it is somewhat uncertain whether the portion which is determined by phenol phthaleïn really exists when dry in the form of hydroxide, and not in the form of oxide, the mean of the last two figures, 0.0023 gram, was adopted in the work which follows. In the case of baric bromide, this correction was calculated for the hydroxide. The corrections are in any case so very small that the possible error introduced by either method of procedure is quite unimportant. Another possible error of about the same magnitude is to be found in the fact that pure baric carbonate is not wholly without influence upon phenol phthaleïn.

In order to observe the behavior of baric chloride under gradually

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* Liebig's Annalen, LXVIII. 215; CVI. 165.

† Schultze, Journ. f. prakt. Chem., [2], XXI. 407.

increasing heat, specimens of very pure material were heated at many different temperatures by means of a Berzelius spirit lamp, and finally raised to redness. The residues were then dissolved in water and the alkalimetric corrections were determined and applied in the manner which has just been described. Below are given the experimental data.

(1.) 3.17+ grams of pure baric chloride which had been dried to constant weight (for twelve hours) at 260°± lost 0.27 milligram on heating to somewhat over 300°, 0.18 milligram more on heating to about 450°, and yet 0.30 milligram upon ignition at a medium red heat. To neutralize the baric hydroxide found upon dissolving the salt, about 0.4 cubic centimeter of the standard solution of hydrochloric acid was required. Since a cubic centimeter of this solution corresponded to a milligram of silver, it is evident that the correction to be added to the weight of baric chloride amounted to 0.09 milligram.

(2.) About 3 grams of baric chloride dried at 400° lost no weight on heating to redness. The alkalimetric correction was +0.12 milligram.

(3.) About 5.0 grams of baric chloride dried at 400° lost 0.17 milligram on heating to dull redness. The alkalimetric correction to be added to the weight of the baric chloride amounted to 0.12 milligram.

(4.) 5.46 grams of baric chloride dried at 250° lost 0.66 milligram on heating to dull redness, 0.22 milligram of this loss being accounted for by the alkalimetric correction.

(5.) A repetition of Experiment 4 showed a loss of 2.0 milligrams between 250° and dull redness, only 0.10 milligram of this amount corresponding to the alkaline earth found.

(6.) About 4.0 grams lost 1.20 milligrams between 300° and dull redness, the alkalimetric correction being only 0.06 milligram.

(7.) 2.61 grams of baric chloride dried at 300° lost 0.40 milligram upon being ignited to a bright red heat in a stream of nitrogen. 0.15 milligram of this loss was due to substitution of oxygen for chlorine.

(8.) 6.37 grams of baric chloride which had been dried at 200° lost 1.75 milligrams of water upon being heated to 300°±, and 1.30 milligrams more upon being partly fused at a bright red heat in a stream of nitrogen. The alkalimetric correction was +0.74 milligram.*

(9.) 3.6 grams of baric chloride dried at 300° lost 0.32 milligram upon being heated to dull redness, only 0.04 milligram being due to loss of chlorine.

(10.) 3.11 grams of baric chloride which had been prepared by drying large clear crystals at 160° lost 0.70 milligram on heating to dull redness. The alkalimetric correction was 0.29 milligram.

(11.) 2.65 grams heated to dull redness lost 0.17 milligram upon being further heated to bright redness. The alkalimetric correction was +0.25 milligram.

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* See page 77 of this paper.

(12.) 1.5 grams heated at 250° lost 1.0 milligram on fusion in a stream of dry pure hydrochloric acid gas. No trace of alkali or acid was found in the concentrated solution of the residue, but the addition of 0.10 cubic centimeter of hundredth normal hydrochloric acid made the neutral solution perceptibly acid to methyl orange.

(13.) 5.36 grams dried at dull redness lost no weight on fusion in hydrochloric acid at bright redness. The residue was wholly neutral.

(14.) 3.92 grams dried at dull redness lost 0.13 milligram on fusion in hydrochloric acid. The heat was so great that the crucible was attacked.

(15.) 4.28 grams of baric chloride dried at dull redness *gained* 0.23 milligram on partial fusion in hydrochloric acid. This specimen, as well as the previous one, was absolutely neutral.

ACTION OF HEAT ON BARIC CHLORIDE.

No. of Exp.	About 200°.	About 250°.	About 300°.	About 400°.	Dull Redness.	Bright Redness.	Fused in HCl.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent
1		+0.021	+0.012	+0.006	−0.003		
2				−0.004	−0.004		
3				+0.001	−0.002		
4		+0.009			−0.004		
5		+0.038			−0.002		
6			+0.029		−0.002		
7			+0.014			−0.006	
8	+0.036		+0.009			−0.011	
9			+0.008		−0.001		
10	+0.013				−0.009		
11					−0.003	−0.010	
12	+0.066						0.000
13					0.000		0.000
14					+0.003		0.000
15					−0.005		0.000
Aver.	+0.038	+0.023	+0.014	+0.001	−0.003	−0.009	0.000

The foregoing table contains a summary of all the experiments, reduced to a common basis. Thus the column headed "Dull Redness" shows that on the average baric chloride ignited at about 500° or 600° loses three parts in one hundred thousand of its weight. The true weight of the baric chloride was computed in each case by adding the alkalimetric correction to the last weight taken; and then the percentage of excess or deficiency in weight was computed for each temperature and tabulated in its appropriate place.

The variations noticeable in the amounts of water retained at the lower temperatures are probably in great part due to the varying hygroscopic condition of the atmosphere at the time of drying, as well as to inaccuracies in the temperatures recorded.

There are necessarily three standards for determining the true weights of baric chloride forming the basis of the table above: one involves the weight of the salt ignited at dull redness plus the alkalimetric correction (Experiments 1, 2, 3, 4, 5, 6, 9, and 10); another involves the weight of the salt ignited at bright redness plus the same correction (Experiments 7, 8, and 11); and the third involves the weight of the salt fused in hydrochloric acid, without any correction (Experiments 12, 13, 14, and 15). A comparison of the results of Experiments 11, 13, and 15 with all the earlier experiments is sufficient to show that the three standards are very nearly, if not quite, identical; in other words, that baric chloride which has been dried at dull redness, or even at 400°, does not lose an essential amount of water upon being heated nearly to 900°. Nevertheless, below 400° — which is about the point at which the salt begins to show signs of partial decomposition — very noticeable amounts of water appear to be held by the so called anhydrous salt.

The conclusion regarding the expulsion of water from the baric chloride is so important that it seemed desirable to prove it in another way. Hence two determinations of the water of crystallization of perfectly homogeneous powdered pure baric chloride were made by two distinct methods: —

(16.) In the first case 3.10784 grams (in vacuum) of the powdered crystals were dried at a medium red heat by means of a spirit lamp to the constant weight of 2.64851 grams (in vacuum) and cooled in a vacuum over phosphoric anhydride. The solution of this salt required 1.00 c.c. of standard hydrochloric acid (of which the cubic centimeter corresponded to a milligram of silver) to render it neutral to phenol phthaleïn, and 0.85 c.c. more to reach the neutral point with regard to methyl orange.

Hence the alkalimetric correction is found to be 0.00025 gram, and after adding this weight to the observed weight of the dried salt, the true per cent of water present in the original crystals is found to be 14.7717.

(17.) Again, 5.02356 grams (in vacuum) of the same sample were dried in a platinum crucible at about 400° by means of the spirit lamp, and then fused in a stream of pure dry hydrochloric acid gas in a double crucible. The constant outflow of hydrochloric acid was sufficient to prevent the absorption of sulphuric acid from the products of the combustion of the illuminating gas, hence it was possible to use this source of heat. Indeed, the highest temperature obtainable by means of a powerful Bunsen burner is required to fuse the salt. After fusion, the salt was found to weigh 4.28148 grams (in vacuum), having lost 14.7720 per cent.

These results (14.7717 and 14.7720) agree within the limit of the probable experimental error; therefore very satisfactory confirmation is given to the conclusion arrived at before. Hence baric chloride is a compound of sufficient definiteness to form a very satisfactory basis for the determination of the atomic weight of barium.

The other properties of the salt — its solubility in water and insolubility in alcohol, the specific gravity of its solution, and so forth — have been studied by Gay Lussac, Gerlach, Karsten, Kopp, Mulder, and many others, and further remark upon them is unnecessary here.

PREPARATION OF MATERIALS.

Baric Chloride. — The ready crystallization of baric chloride upon the addition of alcohol to a strong aqueous solution of the salt furnishes an admirable method for the preparation of baric chloride in a pure state. This method of crystallization was freely resorted to in preparing the pure salt used in the preliminary experiments; but the details of the preparation need not be dwelt upon. The spectroscopic test of the purity of the salt has already been described at length.* The purest specimens of baric chloride used in the final experiments were prepared by three methods. According to the first of these methods, after the salt had been crystallized two or three times from water, it was precipitated five times in succession by the addition of strong pure hydrochloric acid to its concentrated aqueous solution. Each time the mother liquor was wholly discarded, and the crystals were carefully drained. The last precipitate was then dissolved in water, and reprecipitated twice successively by means of the purest alcohol. These and the subsequent operations were conducted in platinum vessels. A portion of the salt thus formed (I.a) was used for Analyses 22, 25, 31, and 32. The remainder of the crystalline powder was washed four times with pure alcohol on the filter pump, dried, ignited, and fused in a large platinum crucible. The translucent cake of anhydrous baric chloride was dissolved in the purest water, and the solution was allowed to stand until it had become neutral. After having been filtered from the baric carbonate, which was of a faintly brownish tinge because of the presence of impurity taken from the platinum during the fusion, the baric chloride was precipitated twice more by means of alcohol. The last crystals were dissolved in the purest boiling water, recrystallized by cooling, and finally washed once with cold water. The very pure salt thus formed was used for Analyses 20, 21, 33, and 35 (Sample I.c). The last mother liquor was freed from most of its salt by the addition of pure alcohol; and the very small amount of salt remaining in solution was recovered by the evaporation of the large volume of alcoholic solution and analyzed (Sample I.b, Analysis 34).

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* These Proceedings, XXVIII. 7.

The second chief specimen of baric chloride was treated in a different way. A large quantity of the commercially pure salt ("purissimum") was dissolved in water, and was then evaporated nearly to dryness with excess of pure hydrochloric acid on a steam bath, to decompose the thiosulphuric acid which is usually present. The hot dilute solution of the residue was treated with an excess of hydrogen sulphide, and the whole allowed to stand in the dark for a long time in a tightly corked stout flask. The clear supernatant liquid was siphoned off from the trace of precipitate and made alkaline with baric hydroxide which had been recrystallized six times.* After a suitable time the clear liquid was again decanted and filtered from the sulphides insoluble in the alkaline solution, and all the sulphur from the filtrate was expelled by boiling with hydrochloric acid. The resulting solution was of course free from the heavy metals, but it contained marked traces of calcium, strontium, sodium, potassium, and possibly magnesium. After two successive crystallizations from water the salt was still found to contain very small amounts of these metals, but after two precipitations by alcohol the spectroscope was unable to show any impurity in it except a trace of the ever present sodium, upon very careful testing. The two hundred grams of pure salt thus obtained were then ignited in small portions at a dull red heat. The residue was dissolved in a platinum dish and crystallized, and the crystals were dissolved in pure water. After filtration the solution was acidified by hydrochloric acid and again brought to crystallization. A portion of the salt thus formed (Sample II.a) was used for Analyses 19, 26, 30, and 36, while the remainder was again ignited in platinum, and was recrystallized twice more after filtration and very faint acidification with hydrochloric acid. The last mother liquor was evaporated to dryness in platinum, and served for Analyses 23, 27, and 37 (II.b). The purest crystals were partly dried over a steam bath, powdered in an agate mortar, and exposed to a moist atmosphere until constant in weight. These crystals (Sample II.c) served for Analyses 28, 29, 38, 39, 40, and 41. An essentially similar preparation, containing somewhat more occluded water, was used for Analyses 42 and 43.

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* See these Proceedings, XXVIII. 19.

A third sample of baric chloride was prepared from a part of the carbonate used for the preparation of baric bromide, and hydrochloric acid which had been distilled twice in platinum. This was purified in the usual fashion, and served for Analysis 24.

These preparations each gave every evidence of being pure. After most careful fractional separation of the greater part of the barium no trace of calcium or strontium could be found, even in large samples, by means of the spectroscope. The trace of sodium visible undoubtedly crept in during the fractional treatment used to prepare the specimen for spectroscopic examination, for the salt itself before the fractionation showed no more sodium than the surrounding air. The effort was made wholly to free the salt from silica by means of repeated ignition and solution, and the use of platinum vessels; but no proof can be given that it did not contain one or two parts in a hundred thousand of this impurity. The quantitative comparison of these preparations which is made further on, furnished conclusive proof of their similarity, at any rate. If the results are reduced to the basis of 100.000 parts of argentic chloride, and arranged according to the sample of baric chloride used, the following averages are obtained.*

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* From these determinations all those made according to Stas's first and second methods have been omitted, since these methods proved to be unsatisfactory. Hence Preparation I.b is not represented in the table. The high result from Sample II.a (Experiments 26 and 36 are parts of the same analysis) was due to a slight mechanical error.

				Parts of Baric Chloride corresponding to 100.000 parts of Argentic Chloride.
Preparation	I.a,	Experiments	22, 25,	72.649
"	I.c,	"	20, 21, 35,	72.651
"	II.a,	"	26, 36,	72.668
"	II.b,	"	23, 27, 37,	72.650
"	II.c,	"	28, 29, 38, 39, 40, 41, 42, 43,	72.657
"	III.	"	24,	72.650
		Total average,		72.654

It may be remarked that the purest specimen (Preparation II.c) gave an average result which is very close to the average of all the specimens.

Silver. — A number of different preparations of this metal, which served as one of the fundamental standards of reference, were used during the course of the work. For the final experiments pure argentic chloride remaining from earlier work was reduced by means of pure sodic hydrate and invert sugar, the invert sugar having been prepared in the first place by heating a strong solution of the purest obtainable cane sugar with a little hydrochloric acid at 100°. After a very thorough washing the metal resulting from this reduction was fused upon hard-wood charcoal in the flame of an ordinary blast lamp, and divided into two parts.

One half of this silver was purified at once by electrolysis according to the manner described in a former paper,* and was used in Analyses 30, 31, 32, 35, 36, and 37. The other half was dissolved in the purest nitric acid, and precipitated again with hydrochloric acid; then the argentic chloride was digested with aqua regia, very thoroughly washed with water, and again reduced to the metal. The last product was fused into large buttons upon sugar charcoal, and purified by electrolysis as before. The current obtained from seven or eight gravity cells is amply sufficient for the purpose. This doubly refined silver was used in Experiments 33, 34, 38, 39, 40, 41, and 43.

The silver used in Experiment 42 was prepared in the first place by Mr. H. F. Brown, according to the cuprous ammonic sulphite method of Stas.† Although the substance thus prepared gave every outward evidence of perfect purity, it was once again purified, this time by means of the electrolytic method used in the case of the previous specimens.

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* These Proceedings, XXVIII. 22.

† Untersuchungen, etc. (Aronstein), pp. 34 and 113.

The three samples of beautiful crystals of silver thus obtained by electrolysis naturally contained a minute amount of imprisoned mother liquor, which is best expelled by fusion. Many precautions were taken to prevent the absorption of an impurity during this process.

In the first trials pure hard-wood charcoal was used to support the metal during its fusion in the flame of the ordinary blast lamp (Experiments 30, 31, and 32). Afterwards a cupel of sugar charcoal was substituted for the wood charcoal. Such cupels are readily made by mixing finely powdered pure sugar charcoal with about a third of its weight of pure powdered sugar, and igniting in closed moulds. The silver used in Analyses 35, 36, 38, 42, and 43 was fused in this way.

A possible absorption of sulphur from illuminating gas being feared, a number of buttons of silver were fused upon the sugar charcoal cupels by the use of a blast lamp in which only pure alcohol, vaporized in a steam bath, was burnt. Such silver was used in Experiments 33, 34, 37, 39, and 40. All of these specimens of silver had been cooled with care in the centre of a strongly reducing flame, to prevent the absorption of oxygen; and any button which showed a trace of such absorption was of course discarded. Proof has already been given * that no oxygen is held after such treatment; but in order to "make assurance doubly sure" three grams and a half of the purest crystals were placed upon a boat made of sugar charcoal, enclosed in a stout porcelain tube, and fused in a vacuum (Experiment 41).

The results obtained from these different varieties of silver may well be recorded here, although the details must be reserved until nearly the end of the present paper. The first specimen of silver fused upon wood charcoal was used in experiments which were vitiated by other serious errors, so that the results from it need not be given. The figures given below represent the amount of silver required exactly to precipitate 100.000 parts of baric chloride.†

(1.)	First	specimen,	sugar charcoal,	illuminating gas,	103.600
(2.)	"	"	"	alcohol,	103.604
(3.)	Second	"	"	illuminating gas,	103.600
(4.)	"	"	"	alcohol,	103.599
(5.)	"	"	"	fused in vacuum,	103.599
(6.)	Third	"	"	illuminating gas,	103.600
				Average,	103.600

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* These Proceedings, XXV. 198.

† The results obtained from Stas's second method, described later, are omitted from this series.

Of these figures (2), (5), and (6) represent single results, and the other figures represent averages. Since a number of samples of baric chloride and a number of different methods of comparison were used in the individual cases, the averages, which to some extent eliminate the differences, are more reliable than the single results. It is evident that the different varieties of silver were quite as nearly alike as the accuracy of our present processes demands.

The investigation of the silver closed with a direct determination of the amount of sulphur present in a sample which was purposely made under conditions as favorable as possible for the retention of this impurity. Twelve grams of silver, which had been prepared by the sulphite method and fused three times successively for a long period in the flame of an ordinary blast lamp, were dissolved and precipitated by electrolysis in a solution of silver nitrate prepared from the same silver. The residual electrolyte, which must have contained all the sulphur, was much diluted, freed from silver by the addition of hydrochloric acid, and evaporated on the steam bath to free it from nitric acid. This solution yielded 1.4 milligrams of baric sulphate, corresponding to 0.2 milligram of sulphur. Hence under these conditions the silver held only $\frac{1}{60,000}$ of its weight of sulphur; and it is fair to conclude that according to the usual method of subjecting the silver only to a single brief fusion not more than $\frac{1}{200,000}$ of its weight would be absorbed. This result is in entire accordance with the quantitative and qualitative results already described; it shows that silver fused once in illuminating gas may be used without appreciable error for all ordinary work.

The preparation of pure water, alcohol, sulphuric and nitric acids, and all other necessary materials, has been discussed in previous papers.*

Standard Solutions. — Several standard solutions were so constantly used during the research that they may well be described at the beginning. In the first place, exactly a gram of silver was dissolved in a slight excess of nitric acid, with the usual precautions,† and diluted exactly to a litre. A solution of pure hydrochloric acid was then made of equivalent strength by comparison with pure sodic carbonate, and verified by comparison with the silver solution. This last comparison is not easily made, for the argentic chloride separates but slowly from a solution so dilute. It was found most convenient to add a very slight excess of silver, to warm, agitate, and filter the solution, and to determine the excess in the filtrate by means of an equivalent solution of ammonic sulpho-cyanate, after the method of Volhard. Sanger* has pointed out that the solubility of argentic chloride seriously affects the accuracy of this method unless the argentic chloride is filtered off before the addition of the sulpho-cyanate; and the experience of this Laboratory had independently led to the same conclusion. It is to be hoped that Clemens Winkler observed this precaution in his interesting analyses of cobaltous and nickellous chloride;† if not, the atomic weights obtained are probably too high.

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* These Proceedings, XXVI. 245–249; XXVIII. 23.

† Ibid., XXV. 198; XXVIII. 24.

The three equivalent solutions of argentic nitrate, hydrochloric acid, and ammonic sulphocyanate each corresponded exactly to a milligram of silver for each cubic centimeter. These solutions are referred to whenever a standard solution is mentioned below.

It is needless to say that the measuring apparatus was all calibrated with great care; moreover, for the final experiments the solutions were weighed in small flasks provided with tightly fitting graduated pipettes, as well as measured. This last precaution was hardly necessary, however. Of course, the ordinary methods of volumetric analysis are not applicable to the determination of atomic weights; but when the greater part of a reagent has been weighed out, the last few milligrams may be added by the measurement of a very dilute solution with an accuracy quite equal to that obtainable upon a balance.‡

Ratio of Baric Chloride to Baric Sulphate.

It is well known that such a ratio as that of baric chloride to baric sulphate could form at best but a very poor basis for determining the atomic weight of barium.§ An experimental error in the process is necessarily magnified many times when referred to the constant sought. Nevertheless, since five distinguished chemists have tried this method, it was thought expedient to attempt it, in order to show if possible the cause of the great discrepancies in their results.

The investigation of the ratio occupied several months, but the report of it will be greatly abbreviated. The principal cause of error was found in the very decided occlusion of baric chloride by baric sulphate, a fact which has already been discussed in a previous paper.* This cause of error was never wholly avoided, although by repeated treatment of the baric sulphate with sulphuric acid, all but a few tenths of a milligram of chlorine were found to be expelled. Whether or not the baric chloride is occluded in the form of a so called "solid solution," as E. A. Schneider suggests in a recent paper with regard to the occlusion of ferric sulphate by baric sulphate,† the fact remains that an appreciable amount of baric chloride is very firmly held. Possibly nothing short of the true solution of all the baric sulphate in sulphuric acid could drive off all the chlorine; and such treatment would be likely to introduce errors as large as the one which it would obviate.

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* These Proceedings, XXVI. 24.

† Zeitschr. Anorg. Chem., IV. 10.

‡ This point, among others, seems to have been misunderstood by G. Hinrichs, of the College of Pharmacy, St. Louis. (Chem. News, LXVIII. 171.)

§ Ostwald, Allgemeine Chemie, I. 23. These Proceedings, XXVIII. 11.

Besides this inclusion of baric chloride, which tends to raise the apparent atomic weight of barium, another circumstance, the solubility of baric sulphate in water, may work in the same direction. This second cause of error was quite eliminated in the present work. A third cause of error with an opposite tendency exists; namely, the obstinacy with which baric sulphate retains the last traces of the excess of sulphuric acid and water used to precipitate it. It must be borne in mind that the retention of 0.2 milligram of either substance counterbalances numerically the retention of nearly two milligrams of baric chloride.

Two series of determinations were made, one by the direct addition of pure sulphuric acid to a concentrated solution of pure baric chloride in a platinum crucible, the other by precipitation in dilute solution after the usual fashion. In the latter case the baric sulphate in the filtrates, usually amounting to about a milligram and a half, was determined by evaporation in large platinum dishes. In each series every specimen of baric sulphate was of course heated with successive drops of pure sulphuric acid at a dull red heat until the weight became constant. Eight experiments which were not complicated with mechanical errors are recorded in the note-book. The two series gave the same result, a hundred parts of baric chloride yielding 112.073 parts of baric sulphate. The highest result was 112.087, and the lowest 112.060. Berzelius found 112.175, Turner 112.19, Thomson about 112.15, Struve 112.094, and Marignac 112.011.

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* These Proceedings. XXVI. 258.

† Zeitschr. für Physikal. Chem. (1892), X. 425.

Owing to the chemical errors which have just been pointed out, the results given above are of no real value. For this reason the individual data are omitted. The uncertainty of the result 112.073 is probably as much as a unit in the second decimal place; therefore the atomic weight of barium computed from it, 137.43, cannot be relied upon to within 0.2. The different errors tend to eliminate one another, so that the result is by chance near the true one.

SOLUBILITY OF ARGENTIC CHLORIDE.

Since it is evident that no satisfactory results are to be obtained from the ratio just discussed, the careful investigation of the ratios of silver and argentic chloride to baric chloride assumes even greater importance than before.

The solubility of argentic chloride is the most serious difficulty which is to be overcome in this investigation. Gay Lussac knew that the filtered liquid which remains after mixing equivalent amounts of solutions of argentic nitrate and a chloride invariably gives a precipitate with an excess of either reagent, showing that some argentic chloride must remain in solution. Mulder, in 1857,* recognized very clearly the same fact, and pointed out, with the help of a great number of detailed experiments, just what influence this fact has upon the titration of silver by Gay Lussac's method.

Mulder wrongly ascribed the solubility of argentic chloride to the presence of the alkaline nitrate resulting from the decomposition, for he believed that the curdy precipitate was wholly insoluble in pure water, or in water acidified with a reasonable amount of nitric acid. Six or eight years later Stas,† without knowing of Mulder's work, clearly recognized the difficulty, but fell into serious blunders in interpreting it. Before 1872, however, when his noted researches on the "chemical statics" of argentic chloride and bromide began to appear,‡ he had become familiar with Mulder's work, and had adopted many of his points of view.

In these last reseaches Stas found that freshly precipitated voluminous argentic chloride was soluble to a very large extent (over ten milligrams to a litre) in the purest water, and that nitric acid or the alkaline nitrates had no appreciable effect upon the solubility. The pulverulent precipitate obtained by continual shaking he found to be much less soluble, only 0.7 milligram being dissolved by a litre of pure water. Nitric acid increases to a sensible degree this last quantity, the increase being approximately proportional to the amount of acid present.

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* Mulder, "Essayeer-Methode van het Zilver," Scheikundige Verhandelingen en Onderzoekingen, 1 Deel, 1 Stuk, 1857. Translated by Grimm, "Die Silberprobirmethode," Leipzig, 1859.

† "Untersuchungen," etc., translated by Aronstein (Leipzig, 1867), pp. 46, 56, 59, and 295

‡ Annales de Chim. et de Phys., 4th series, XXV. 22; and 5th series, III. 145 and 289.

Mulder knew well that it was possible wholly to precipitate either silver or chlorine by the addition of a sufficient amount of the other reagent, but wrongly assumed that the amount of the reagent required was a direct measure of the solubility of argentic chloride. This misconception probably arose from a theoretical discussion of very doubtful value; its effect was to make Mulder's estimate of the solubility rather excessive. Stas recognized the fact for the first time, that much more silver is required to precipitate the chlorine in solution as silver chloride than is enough directly to combine with it. A very tedious series of experiments led him to the conclusion that for every molecule of argentic chloride dissolved just three molecules of argentic nitrate or of a chloride were required to complete the precipitation. In 1881 Cooke called attention to some of the same facts.*

Much time has been spent during the present research upon the subject, for its importance with regard to the analysis of baric chloride was very evident. The experiments were largely a repetition of Stas's, with occasional variations suggested by the case in hand. Mulder and Stas having wholly done away with the old idea of the insignificance of the action of light on the haloid compounds of silver, the greatest care was taken with regard to the protection of the precipitates from diffused light. Work with them was performed wholly in a dark room lighted by means of illuminating gas shining through thick orange glass; and even here the flasks were always covered by two or three thicknesses of black cloth when left to themselves.

In determining the solubility of argentic chloride a number of experiments were made, first by colorimetric and "opalimetric" methods. The coloration produced by hydric sulphide and the opalescence produced by hydrochloric acid were compared with similar phenomena produced by known amounts of silver. Very much experience is needed to obtain satisfactory results with either of these methods, so that a more direct method of determination was sought.

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* These Proceedings, XVII. 7. Cooke also studied the action of hot water upon argentic chloride.

An opalescent solution produced by the addition of hydrochloric acid or argentic nitrate to a solution of argentic chloride often requires many weeks to deposit its suspended salt, even when warmed and shaken, if the flask is kept wholly in the dark. The effort to evaporate the solution by boiling in vessels partially closed to exclude the dust, proved equally unsatisfactory. Hence in order to weigh very small amounts of dissolved argentic chloride it was necessary to evaporate the solutions upon the steam bath in suitably protected glass dishes. In order to determine the magnitude of any possible errors which might arise from this method of treatment a number of check experiments were made. In the first place dilute solutions of argentic nitrate were evaporated to small bulk with the addition of nitric acid. The evaporated solution was filtered through a small paper, and the ash of the washed filter was dissolved in nitric acid and titrated with a weak standard solution of ammonic sulphocyanate,* after the method of Volhard. Three experiments showed that an amount of silver equal to about 0.02, 0.01, and 0.00 milligram respectively had been retained by the filter. These experiments proved that the precautions taken to prevent dust or foreign materials from reaching the surface of the solutions during the process of evaporation had been sufficient for their purpose; also, that no very important amount of silver was held by the paper.

Having determined these facts, the next step was to determine whether all of a very small known amount of argentic chloride could be recovered. A few preliminary experiments showed that in order to reduce and recover all of the silver by the ignition of the filter paper it was necessary to keep the precipitate in a finely divided state. This end is easily accomplished by using a solution dilute enough to prevent the clotting of the opalescent chloride. Thus one cubic centimeter of the weak standard hydrochloric acid precipitated enough argentic chloride from a slight excess of the nitrate to require after reduction by the burning of the filter 0.97 and 0.99 cubic centimeter of the sulphocyanate solution. Although the evaporation was conducted in dull diffused light, the argentic chloride was not discolored.† These experiments showed that a small amount of argentic chloride could be nearly all recovered from a small volume of solution.

The next experiments were made with large volumes of solutions containing about 0.2 gram of silver, a very little baric nitrate, and a small amount of nitric acid, besides the measured amount of standard hydrochloric acid. Two experiments, after filtration, ignition, and titration as before, indicated that 1.01 and 1.02 milligrams of silver were precipitated by one cubic centimeter of hydrochloric acid, instead of just one milligram. Again, with all the other conditions just the same, 0.50 c.c. of hydrochloric acid precipitated in two cases 0.62 and 0.59 milligram of silver. In order to determine whether the presence of large amounts of baric nitrate might make any essential difference, these experiments were repeated with the addition of five grams of the purest preparation of this salt,* quite free from chlorine. In this way 0.50 c.c. of hydrochloric acid yielded 0.57 milligram of silver and 0.20 c.c. precipitated 0.27 milligram of silver. The last six experiments showed that the presence of a considerable excess of silver in solution causes the precipitation of a slight excess of silver with the chloride.

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* See page 66 of this paper.

† Compare Pohl, Jahresbericht 1851, p. 369. Quoted by Mulder, Silberprobirmethode, p. 19.

Two experiments with neutral solutions treated in the same way showed much more marked gains; one exposed to the air during evaporation for eight hours gained 0.13 milligram of silver; and the other, evaporated for twenty-four hours, the water being replaced from time to time, gained 0.32 milligram. These gains might have been due to the action of organic matter in the absence of nitric acid, or the action of alkali dissolved from the glass; in any case, the necessity of the presence of free acid was shown.

In the work which follows it was several times necessary to evaporate strongly acid solutions of argentic chloride containing only a very slight excess of silver, hence parallel determinations under these conditions were very essential. In this way three successive experiments yielded respectively 0.38, 0.38, and 0.37 milligram of silver, instead of 0.50 milligram, which should have been obtained; one experiment gave 0.52 instead of 0.60, and two more gave respectively 0.90 and 0.93, instead of 1.00. Hence, when much nitric acid and very little silver are present, the amount of metal found is too small instead of too great.

These determinations all together show that the evaporation of solutions of argentic chloride upon the water bath is a process carrying with it small errors, some plus and some minus, which are reasonably constant under constant conditions. They show also that the presence of baric nitrate does not in the least alter the accuracy of the determination, which depends chiefly upon the relative amounts of argentic nitrate and nitric acid present in each case. They moreover furnish a means of correcting results obtained by the method in hand. A solution containing two tenths of a gram of argentic nitrate, three grams of nitric acid, and a very small known amount of argentic chloride, evaporated for four or five hours, yields about 0.00006 gram too much silver, and a similar solution containing only a few milligrams of argentic nitrate yields about 0.0001 gram too little. The bearing of these facts upon the subject will presently be made more evident.

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* These Proceedings, XXVIII. 16, 19.

It was now possible to determine the solubility of argentic chloride less crudely. Half a litre of the purest water, after being shaken occasionally with the purest argentic chloride for two hours, yielded 0.50 milligram of silver, and a similar preparation, which had been allowed to stand for twenty-four hours with more frequent shaking, yielded 0.60 milligram. The solubility of this argentic chloride is thus found to be about 1.5 milligrams per litre. The result is not far from the mean of the colorimetric tests.*

To determine the influence of nitric acid upon the solubility, four grams of this substance were added to over a litre of pure water, and the mixture was shaken with the same argentic chloride. 300 cubic centimeters of the solution yielded 0.47 milligram of silver, and two portions of 400 cubic centimeters each yield 0.56 and 0.57 milligram of silver respectively. After adding the appropriate correction, and taking the mean of these determinations, the solubility is found to be about 2.3 milligrams per litre.

In a number of analyses exactly equivalent amounts of baric chloride and argentic nitrate in dilute solution were shaken together, and both chlorine and silver were determined in the filtrate. These analyses were primarily to determine the atomic weight of barium, and will be described later; but since the chlorine was found to be present in the filtrate in amounts almost exactly equivalent to the silver, they may be used also to measure the solubility of argentic chloride in solutions containing about 2.5 cubic centimeters of nitric acid, and 3 to 8 grams of baric nitrate. In one case, where the solution had been shaken with the argentic chloride for ten days, the solubility was found to be about 1.6 milligrams per litre; in another, violently shaken, but allowed to stand for a shorter time, it was found to be about 1.7

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* It is noteworthy that Kohlrausch and Rose have found the solubility of argentic chloride to be 1.52 milligrams per litre at 18°. This determination was based upon the electrical conductivity of the solution. (Zeit. Physikal. Chem., XII. 234.)

milligrams per litre; and in a third, much less violently shaken, but allowed to stand for a week, it was as much as 2.7 milligrams per litre. In each of these cases the temperature was about 20°.

These results are, as one would expect, between the limits set by Stas; for the precipitate was in the state usually observed, having lost its first flocculence, and not having been wholly converted into powder.

A careful series of experiments was made to confirm Stas's statement that the chloride is absolutely insoluble in water containing an excess of argentic nitrate. It is not needful further to describe these experiments, except to state that the confirmation was wholly satisfactory. In the course of this work I was able to detect repeatedly one part of chlorine in thirty million parts of water, by careful comparison in strong sunlight after treatment with excess of argentic nitrate. The very faint opalescence of course very soon disappears, owing to the blackening of argentic chloride by the powerful light.

Ratio of the Chlorides of Silver and Barium.

The properties of the two chlorides having been studied as far as they are concerned in the present work, it was now possible to compare their molecular weights. Very definite advice with regard to the precautions necessary in such a comparison has been given by Stas,* and most of his suggestions have been found of use. One recommendation, however, although most useful for ordinary work, is of questionable propriety when applied to the most precise work. In order to prevent argentic chloride from being dissolved by the water used for washing it, Stas advises the exclusive use of a very dilute solution of argentic nitrate for the purpose.† I have found it very difficult wholly to free argentic chloride from traces of the nitrate, even by long continued shaking with pure water, and of course this difficulty is increased by the presence of additional impurity. The small amount of argentic nitrate which is certain to be left behind, according to the method of Stas, decomposes and blackens a little of the chloride upon fusion, even in the dark; and no suitable correction can be applied to counteract the error. Accordingly, pure water was always used for the final washings during the present work.

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* Mém. de l'Acad. Belg., Vol. XLIII. Part II. p. 66.

† Professor Cooke also suggested this method of procedure. (These Proceedings, XVII. 7.)

These wash waters were all evaporated, and the small amount of argentic chloride present was determined in the manner which has already been described. It is thus tolerably certain that the necessary errors of the analytical process did not exceed the tenth of a milligram.

In two preliminary experiments very pure baric chloride was ignited at a dull red heat to constant weight, dissolved in water, and corrected for the amount of alkali found. It was then precipitated, when perfectly cool, by pouring it into a slight excess of silver dissolved in nitric acid, and diluted with about forty times its weight of cold water. The precipitate was very thoroughly shaken for several days, and washed by decantation until the wash water was no longer acid. It was then transferred with great care to a Gooch perforated crucible, washed for some time longer, dried at 180°, and weighed. Both of the precipitates were slightly colored, and each lost about $\frac{1}{10000}$ of its weight upon fusion in a covered porcelain crucible. In calculating the results it was necessary to subtract the amount of argentic chloride equivalent to the small *excess* of hydrochloric acid usually added in determining the amount of alkali formed by the ignition, as well as to add the amount of argentic chloride found in the wash water. The corrected results are given below, the details having been omitted; but the particulars will be given with regard to all the important determinations.

PRELIMINARY DETERMINATIONS.

$2 AgCl : BaCl_2$.

No. of Exp.	Corrected Weight of Baric Chloride.	Corrected Weight of Fused Argentic Chloride.	100,000 parts of Argentic Chloride correspond to n parts Baric Chloride.	Atomic Weight of Barium.
	Grams in Vacuum.	Grams in Vacuum.	$n =$	
18	6.7295	9.2637	72.644	137.411
19	5.4597	7.5161	72.640	137.400
	Average,	. . . .	. . . .	137.406

Since the experiments were carried on in the dark, the purplish color of the fused argentic chloride indicated that argentic nitrate had been occluded, in spite of the considerable care used in washing the precipitate. In order to determine whether this occlusion had been due to the concentration of the silver solution, an experiment was made by pouring a solution of a definite amount of pure baric chloride into a very strong solution of argentic nitrate. 2.6088 grams (corrected) of baric chloride yielded 3.5929 grams (corrected) of carefully washed argentic chloride. The ratio deduced from these figures is $2\,AgCl : BaCl_2 = 100 : 72.609$, a result almost $\frac{1}{2000}$ lower than the last; and the consequent value of the atomic weight of barium is only 137.31. The argentic chloride was of a very deep purple color.

The outcome of these experiments showed the necessity of Stas's usual practice of having the silver solution very dilute; in the subsequent work the dilution was usually 1 : 100, and sometimes even greater.* Moreover, the nitrate was always in future poured gradually into the baric chloride, so that until the very last an excess of chlorine should be present in the solution.

In the first series of the final group of experiments the baric chloride was ignited at a dull red heat in air or nitrogen; in the second series the salt was ignited and fused at a bright red heat in a stream of pure hydrochloric acid; and in the third it was not ignited at all. The simplest manner of explaining the method of procedure adopted in the three series of analyses which follow is to give the detail of one of the experiments.

Experiment 20. Very pure baric chloride, which had been prepared by many successive precipitations from aqueous solution by hydrochloric acid and alcohol (Sample I.c), was coarsely powdered and gradually heated to bright redness by means of a Berzelius spirit lamp in a double platinum crucible. In order to prevent as much as possible the decomposition of the salt, the long continued ignition was conducted in a stream of pure nitrogen. A large part of the salt was fused during the process. After having been cooled for eight hours over phosphoric oxide in a desiccator, the tightly covered inner crucible was rapidly weighed, and the weight of baric chloride was found to be 6.36793 grams in the air. Since the atmospheric pressure and temperature at the time of weighing were respectively 76 c.m. and 20°, the salt would have weighed 6.36900 grams in a vacuum. The solution of the baric chloride in pure boiled water in a large platinum dish was perfectly clear, and the crucible itself was found to have lost only 0.02 milligram in weight. The clear liquid upon being titrated at once with standard hydrochloric acid* was found to require 3.40 cubic centimeters of the solution in order to remove the color of the trace of phenol phthaleïn added, and 0.64 cubic centimeter more to reach the point at which methyl orange began to show an excess of acid. An excess of yet 0.26 cubic centimeter was added in order to be certain of the end-point. According to page 57, the correction to be added to the weight of the baric chloride corresponding to the first addition of acid was 0.71 milligram, while the correction corresponding to the second addition was 0.03 milligram. Hence, the true weight of the baric chloride in vacuum, if none had been decomposed by heat, would have been 6.36974.

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* In some cases Stas used only fifteen to thirty cubic centimeters of water for every gram of silver, in spite of his good advice to the contrary. Mém. Belg., etc., XLIII. Part II. p. 11.

The solution was transferred with the greatest care to a glass stoppered Erlenmeyer flask, and diluted to about one hundred and fifty cubic centimeters with cold water. To it was then gradually added in the dark room the cold solution of about 6.72 grams of silver (about $\frac{1}{50}$ excess). The metal had been dissolved in thirteen cubic centimeters of the purest nitric acid, the lower oxides of nitrogen had been expelled, and the whole had been diluted to over six hundred cubic centimeters.

The precipitate was shaken occasionally with the liquid for several days in perfect darkness; and the filtrate, which could contain no trace of chlorine, was separated by means of the indispensable Gooch crucible. After having been passed several times through the crucible, in order to avoid the loss of any shreds of asbestos, the filtrate was set aside. The precipitate was violently agitated with renewed portions of cold water until the wash water was absolutely neutral, and was then transferred to the crucible by means of a jet of water. The last particles of argentic chloride were removed by shaking the stoppered flask violently with a little water. Subsequent testing with ammonia and nitric acid showed that no argentic chloride remained in the flask. The thirteen hundred cubic centimeters of wash water were evaporated, and the small amount of resulting argentic chloride was collected upon a small washed filter of the best quality. After the rapid ignition of the filter paper in a porcelain dish, the ash was found to contain 0.70 milligram of silver, according to Volhard's method. Hence, 0.93 milligram of argentic chloride had been dissolved. The main mass of the precipitate was dried at 180°; and after having been carefully weighed it was transferred to a porcelain crucible, weighed again, fused in an air bath, and weighed yet again. It is needless to say that organic matter was carefully excluded during all the operations, but nevertheless the argentic chloride was not absolutely colorless after fusion. Perhaps the trace of phenol phthaleïn and methyl orange may have caused a slight decomposition. It will be seen how the introduction of these indicators was avoided before the close of the investigation.

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* See page 66 of this paper.

The final corrected weight of the argentic chloride was found as follows: —

		Grams.
Weight in air of AgCl in Gooch crucible	=	8.76657
Correction to vacuum (T° = 22°, H = 76 c.m.)	=	+0.00062
Weight in vacuum of AgCl in Gooch crucible	=	8.76719
Loss on fusion in porcelain crucible	=	—0.00050
Weight of main mass of fused AgCl	=	8.76669
Weight of AgCl found in wash water	=	+0.00093
Total argentic chloride	=	8.76762
Corresponding to 0.26 c.c. standard HCl added in titration	=	—0.00035
Corrected weight of argentic chloride in vacuum	=	8.76727

Since it seemed hardly probable that either of the chlorides was in this case weighed more accurately than within 0.1 milligram, the fifth place of decimals is omitted below. This practice was always adhered to unless the fifth place seemed to have some significance.

Experiment 20 then leads us to conclude that the ratio of argentic chloride to baric chloride is 8.7673 : 6.3697 = 100.000 : 72.653. Hence, the atomic weight of barium is easily found to be 137.435, a result which agrees almost exactly with that obtained from baric bromide.

The other analyses were conducted in a similar manner. In some cases, where it was suspected that the wash water carried with it a trace of finely divided asbestos, the whole quantity was filtered through a washed filter, and the weight found, if appreciable at all, was added to the weight of the Gooch crucible. The table given below is probably comprehensible without further remark, except perhaps the statement that the two figures given in the third column represent the corrections for the baric hydroxide and baric carbonate respectively.

The weights in the following cases are reduced to the vacuum standard.

RATIO OF ARGENTIC AND BARIC CHLORIDES.

First Series.

No. of Exp.	Baric Chloride weighed.	Alk. cor. See p. 57.*	$BaCl_2$ corrected for Alkali found.	Argentic Chloride found (Fused).	AgCl corresp. to extra HCl.	AgCl in Wash Water.	Total Argentic Chloride.	Ratio 2 AgCl : $BaCl_2$ = 100 : x.	Atomic Weight of Barium.
	grams.	c c.	grams.	grams.	m. gr.	m. gr.	grams.		
20	6.3690	3.4 0.6	6.3697	8.7667	0.35	0.93	8.7673	72.653	137.435
21	3.7764	0.3 0.2	3.7765	5.1973	0.20	0.80	5.1979	72.654	137.440
22	3.5846	0.0 0.7	3.5846	4.9332	0.13	1.10	4.9342	72.648	137.423
23	1.5084	0.3 0.3	1.5085	2.0759	0.24	0.86	2.0765	72.646	137.417
24	3.2160	1.1 0.9	3.2163	4.4254	0.64	2.32	4.4271	72.650	137.429
							Average	72.649	137.428

The second series of determinations is distinguished from the first by the fact that the baric chloride was fused in an atmosphere of pure dry hydrochloric acid, being contained in a platinum crucible provided with a perforated cover. No phenol phthaleïn was added to the salt after its solution, and only a trace of methyl orange, in order to prove its absolute neutrality. Hence, the danger of a slight reduction of silver by compounds of carbon was much lessened. In all other respects the analysis was conducted in a manner similar to that employed in the last series, except that even greater care was used.

RATIO OF ARGENTIC AND BARIC CHLORIDES.

Second Series.

No. of Exp.	Weight of Fused Baric Chloride.	Weight of Fused Argentic Chloride.	AgCl corresp to extra HCl.	AgCl in Wash Water.	Total Argentic Chloride.	Ratio 2 AgCl : $BaCl_2$ = 100 : x.	Atomic Weight of Barium.
	grams.	grams.	m.gr.	m.gr.	grams.		
25	1.52384	2.09730	0.00	0.20	2.09750	72.650	137.429
26	5.36010	7.37590	0.10	0.30	7.37610	72.669	137.481
27	3.92244	5.39771	0.12	1.47	5.39906	72.650	137.429
					Average	72.6563	137.446

* Compare also these Proceedings, XXVIII. 12, also 26.

The third series differed from the two others in that the baric chloride was not ignited at all. In the two analyses thus made, the true weight of the anhydrous baric chloride taken in each case was calculated from the weight of the homogeneous powdered crystallized salt actually weighed. The determinations of the water of crystallization given on page 61, which were made at this time, upon this identical sample, showed with great certainty that the percentage of anhydrous salt present must have been 85.2282. Of course, no indicator of any kind was added to the solution before the precipitation. The argentic chloride after having been fused and cooled was of a most beautiful pearly lustre, without a trace of grayness; and in every respect the analyses appeared to be satisfactory.

RATIO OF ARGENTIC AND BARIC CHLORIDES.

Third Series.

No. of Exp.	Weight of Crystallized Baric Chloride.	Calculated Weight of Anhydrous $BaCl_2$.	Weight of Fused AgCl.	AgCl in Wash Water.*	Total Argentic Chloride.	Ratio $2\,AgCl : BaCl_2 = 100 : x$.	Atomic Weight of Barium.
	grams.	grams.	grams.	milligrams.	grams.		
28	7.00617	5.97123	8.21488	4.0	8.2189	72.6524	137.435
29	3.85330	3.28410	4.51770	2.2	4.5199	72.6587	137.453
					Average	72.6555	137.444

The discussion of all these results will be found under a later head.

Ratio of Metallic Silver to Baric Chloride.

In determining this ratio the solubility of argentic chloride plays a much more damaging part than in the determination of the previous one. The uncertainty may easily become as great as thirty or forty milligrams in the weight of the silver, — an amount so enormous as to render accurate determination apparently impossible. Aside from this uncertainty, due to the existence of the two end-points, the observation of the point at which a drop of one solution or the other absolutely ceases to produce a precipitate is a very trying matter. The physical condition of the observer, and his practice in observation of this sort, have much to do with his determination of the presence or absence of a faint cloud at the top of the vessel under observation. The phenomenon is one which gradually fades away as more and more silver or hydrochloric acid is added, the last opalescence appearing only after some time. Often when no cloud is visible at the end of an hour, a very evident one is to be seen in two hours. The amount of light at hand is also an important factor in the determination. Temperature produces a very important effect on the solubility of argentic chloride; and this effect is tripled when it is referred to the solution which is being added. The results are thus far less satisfactory than similar results obtained with the bromide.

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* Since the excess of silver was very slight, and a portion of the argentic chloride in the filtrate was determined by the evaporation of the strongly acid solution of baric nitrate, it was necessary to apply the correction of +0.0001 gram, described on pages 72 and 73, to the amount of argentic chloride found in the wash water. The values given above have been thus corrected.

For preliminary experiments the method used by Stas in his early analyses * was adopted. The method consisted in the addition of an excess of silver to the solution of baric chloride, a standard solution of hydrochloric acid being used to determine this excess. At first the atomic weight thus obtained corresponded very closely to that obtained by the last ratio, but as the work proceeded the apparent atomic weight of barium steadily rose. The reason for this anomaly was not clear for a long time; but in the end it was evident that the apparent accuracy of the first results had been due to the mutual elimination of two opposite errors. The occlusion of argentic nitrate by argentic chloride tended to require too much silver, and the method of titration required almost equally too much hydrochloric acid. When more care was taken with regard to the dilution of the argentic nitrate, and as the observer became more and more practised in the delicate observation of the end point, the first error steadily decreased, and the second steadily increased. Hence, they no longer counterbalanced one another. A long time was spent in finding that this first method, used by Stas in his early analyses of lithium, sodium, potassium, and ammonium chlorides, was quite false. Even relative results by this method, such as Stas's comparison of the different varieties of silver, can have no important value, because it is wellnigh impossible to make all the conditions absolutely constant. It is almost needless to say that these remarks apply only to this early method, and not to Stas's later work. Naturally he made errors at first. It is much to be regretted, however, that he did not point out more clearly after-

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* "Untersuchungen," etc. Leipzig, 1867.

wards the serious nature of these errors, which he clearly appreciated. Most of the investigations of Stas remain models of precision; and no one who has not attempted practically to follow in his footsteps can form an adequate idea of the greatness of his success.

Stas's study of the "Statics of Argentic Chloride" has been already referred to. As a result of this long and valuable series of experiments, he concluded that the true end-point must be half way between the two end-points obtained by titrating in opposite directions. When this true end-point had been reached, he found that the supernatant liquid was rendered equally opalescent by equivalent amounts of hydrochloric acid and argentic nitrate. These conclusions suggested two possible methods for the solution of the problem before us; and it is worthy of remark that at least one of these methods had been suggested by Mulder fifteen years before Stas's publication.*

The unsatisfactory results obtained by the old method inclined one to subject the newer methods also to a careful testing before going further; accordingly a long series of experiments, not unlike those described by Stas, were instituted to prove them. In the first place, pure thoroughly washed argentic chloride which had been made and kept in darkness was shaken with a dilute solution of pure baric nitrate and nitric acid; and then the two end-points were determined by adding first hydrochloric acid, and afterward argentic nitrate, until no more cloudiness could be observed in either case. The results were not very satisfactory, for a reason which appeared later. Nevertheless, many experiments were made in this way, showing that the observation of Stas was at least approximately true. The observation with regard to the equality of opalescence could not be confirmed at once, because the method requires much practice; but in the end the confirmation of it was much more satisfactory than the previous one. It was clear, however, that both methods depended upon a question of judgment rather than upon definite weighing or measuring.

In default of a more satisfactory method a series of experiments upon the atomic weight of barium was made by determining both end-points and taking the mean as the true one, according to Stas's second method. During this series a curious fact became manifest. As the alternate addition of hydrochloric acid and silver nitrate proceeded, the necessary amount of each solution increased to an enormous degree. For instance, in Experiment 33 below, the first difference between the end-points was 16 milligrams of silver, while the third was as much as 34 milligrams. This change was probably due to the fact that the argentic chloride produced by the successive additions of the solutions was of the more soluble flaky variety, while the greater part of the precipitate had been so thoroughly shaken before as to become much less soluble. A larger amount of the salt in solution naturally required more of each reagent to precipitate it. This phenomenon was the chief cause of uncertainty in the attempt to confirm Stas's results. Probably the reason for his overlooking it lay in the fact that he rarely titrated backward and forward many times with the same solution.

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* Silberprobirmethode, p. 94.

In the experiments tabulated below, the baric chloride was ignited in the air, and the small amount of chlorine lost was allowed for as usual. The calculated and carefully weighed amount of pure silver was dissolved in nearly three times its weight of the purest nitric acid in a Bohemian flask provided with bulb tubes for arresting the spray. The bulbs were washed out into the flask, the nitrous fumes were expelled by heating upon the steam bath for a long time, the contents of the flask were diluted and cooled, and the argentic nitrate was added to the baric chloride in a glass-stoppered flask.

In every case the first readings of the end-points are recorded in the table as being the most trustworthy, although in some cases as much as three weeks were spent upon a single determination in titrating backward and forward. The weights are, as usual, reduced to the vacuum standard.

RATIO OF SILVER TO BARIC CHLORIDE.

FIRST SERIES: STAS'S SECOND METHOD.

No. of Experiment.	Corrected Weight of Anhydrous Baric Chloride.	Mean Amount of Silver required.	Difference between Extreme Amounts of Ag.	Ratio $2\,Ag : BaCl_2 = 100 : x$.	Atomic Weight of Barium.
	grams.	grams.	grams.		
30	5.9717	6.1872	0.0032	96.517	137.431
31	5.4597	5.6580	0.0140	96.495	137.383
32	3.4728	3.5988	0.0050	96.499	137.389
33	9.0726	9.4010	0.0160	96.507	137.408
34	0.6950	0.7199	0.0029	96.541	137.482
				96.511	137.419

The objections to this method have been stated already; accuracy with it is a question of judgment and keenness of sight upon the part of the observer, and absolutely constant conditions of temperature, illumination, and agitation on the part of the substance in the flask. Although great pains were taken to have these conditions as constant as possible, it cannot be claimed that they were absolutely so. Moreover, the method is so hopelessly tedious that it was finally abandoned.

In the search for a new method, the following scheme was devised. A slight excess of one or two decigrams of silver over and above the amount required to precipitate a weighed quantity of baric chloride was weighed out with the greatest care. This was dissolved and added to the baric chloride as before. The mother liquor, containing argentic nitrate, baric nitrate, and nitric acid, *but no trace of chlorine*, was filtered off with the greatest care through asbestos, and the precipitate was thoroughly shaken and washed with pure water. The wash waters were collected separately and evaporated on the steam bath in a suitably covered dish to small bulk. The trace of argentic chloride thus precipitated from them was filtered off and washed upon a very small filter, and the few milligrams of argentic nitrate in the filtrate were added to the original mother liquor. From this mixture of liquids all the silver was precipitated and weighed as argentic bromide.* The excess of silver originally weighed out is thus very simply calculated from the weight of the argentic bromide without involving a personal equation of any sort. Three analyses were made according to this method.†

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* For the preparation of the hydrobromic acid used, see these Proceedings, XXVIII. 17. The precipitate was assumed to contain 57.445 per cent of silver.

† After the present paper had gone to press, notice was received from Professor Mallet that Stas had suggested to him, in a letter dated January 27, 1887, a method very similar to the one just described. J. W. Mallet, Stas Memorial Lecture, p. 33. [November 12, 1893.]

RATIO OF SILVER TO BARIC CHLORIDE.

SECOND SERIES: FIRST NEW METHOD.

No. of Exp.	Corrected * Weight of Baric Chloride.	Silver weighed out.	Weight of Silver found in Filtrate. †	Weight of Silver corresponding to $BaCl_2$.	Ratio $2\,Ag : BaCl_2 = 100 : x$.	Atomic Weight of Barium.
	grams.	grams.	grams.	grams.		
35	6.36974	6.72090	0.12097	6.59993	96.512	137.419
36	5.36010	5.73383	0.18154	5.55229	96.539	137.476
37	3.92244	4.08060	0.01680	4.06380	96.522	137.440
				Average	96.524	137.445

A second new method of accomplishing the desired object consisted in the actual determination of the silver and chlorine left in a solution obtained by mixing amounts of baric chloride and argentic nitrate supposed to be equivalent.

The solution and first five wash waters filtered off from such a carefully prepared mixture, which had been shaken occasionally for about a week, were thoroughly mixed and divided exactly in half. One half was evaporated with hydrobromic acid, and the other with argentic nitrate, and the small amounts of argentic bromide and chloride were determined by reduction and the use of Volhard's method.

Subsequently it appeared that there was a slight error in the method, due to the difficulty of determining accurately such small quantities of substance. By the evaporation of solutions known to contain nothing but pure argentic chloride, it was found that the amount of silver obtained was always a little less than enough to correspond to the chlorine. Several experiments showed that the error from this cause amounted to very nearly one tenth of a milligram, hence this amount is added below to the amount of silver found in the half of the filtrates which was evaporated with hydrobromic acid.

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* For the corrections, see page 79 of this paper. These three analyses are portions of Experiments 20, 26, and 27.

† This weight, computed from the argentic bromide, has been corrected for a very slight excess of hydrochloric acid. The correction, which was of course added, amounted to 0.00026 gram in the first case, 0.00007 in the second, and 0.00009 in the third. Compare data on page 79.

RATIO OF SILVER TO BARIC CHLORIDE.

Third Series: Second New Method.

No. of Exp.	Corrected* Weight of Baric Chloride.	Weight of Silver taken.	Silver found in one half of Filtrate, plus correction of 0.0001 gram.	Silver corresponding to Chlorine found in the other half of Filtrate.	Corrected Silver required by Baric Chloride.	Ratio 2 Ag : $BaCl_2$ = 100 : x.	Atomic Weight of Barium.
	grams.	grams.	grams.	grams.	grams.		
38	4.2815	4.43558	0.00080	0.00076	4.4355	96.528	137.453
39	2.6488	2.74417	0.00063	0.00054	2.7440	96.531	137.459
40	5.9712	6.18547	0.00065	0.00118	6.1865	96.520	137.436
41	3.2841	3.40245	0.00060	0.00052	3.4023	96.526	137.449
					Average	96.526	137.449

During a large part of the considerable time consumed by these analyses, experience with the comparison of opalescence was gradually being acquired. The details of this method have been so fully given by Stas that further mention of them need not be made here. For the final experiments the baric chloride was dissolved in a large amount of water, and decomposed by a very slight excess of argentic nitrate in very dilute solution, the silver having been weighed and dissolved with the greatest care. After the mixture had been shaken occasionally for a number of days, it was allowed to settle, and two portions of twenty-five cubic centimeters each were taken out with a pipette. A little hydrochloric acid produced a more evident opalescence in one of these portions than an equivalent amount of silver did in the other, showing that too much silver had been taken. Known amounts of hydrochloric acid were therefore added very gradually to the main mass of the liquid, until, after agitation and settling, two portions of the clear supernatant liquid treated respectively with argentic nitrate and hydrochloric acid showed like intensity of opalescence. This similarity of opalescence was further confirmed by measuring the heights of parallel unknown columns of the two liquids which had been adjudged equally cloudy. From the average of a great number of readings, one could feel reasonably certain of the result within two or three per cent, corresponding to an error of not over one or two tenths of a milligram of silver in the volume of solution used.

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* The last two of these determinations formed a continuation of Experiments 28 and 29 already given, and the calculation of the amount of anhydrous baric chloride need not be repeated. The actual weight of ignited baric chloride taken in Experiment 39 was 2.64851 grams (in vacuum); but this was found to require a correction due to loss of chlorine amounting to 0.00025 grams. The corrected weight is given in the table. Since the salt used in Experiment 38 was ignited in hydrochloric acid gas, no correction was necessary. In Experiment 38 the weight of silver given in the third column is 0.00020 gram less than the amount actually weighed, because 0.20 cubic centimeter of standard hydrochloric acid was added to determine the neutrality of the baric chloride before the precipitation.

For example, in the first analysis recorded below, it was found in three preliminary trials that about 0.30 cubic centimeter of the standard hydrochloric acid should be added to the remaining mixture in order to reach the desired point. This amount was therefore added, and two portions were again taken out, treated as before, and compared.

Solution to which HCl was added.					Solution to which $AgNO_3$ was added.
9.5 c.m.	in height	appeared	equal	to	10.0 c.m.
10.5 "	"	"	"	"	10.0 "
10.3 "	"	"	"	"	10.0 "
10.1 "	"	"	"	"	10.0 "
9.2 "	"	"	"	"	10.0 "
Average, 9.9 "	"	"	"	"	10.0 "

This average shows that the equality of cloudiness was now within the probable experimental error.

It was borne in mind, however, that a fifth of the original solution had been used up in the preliminary tests. Hence, the true amount of hydrochloric acid which should have been added to the original solution must be $\frac{5}{4} \times 0.3 = 0.375$, or practically 0.4 cubic centimeter.

Hence, since this amount of hydrochloric acid is of course a direct measure of the excess of silver originally taken, 0.4 milligram should be subtracted from the original weight.

It is needless to say that all possible care was used in these final determinations. The reiteration of the countless details would be wearisome, and hence these details are left to be inferred from what has been already written. The method is the simplest and easiest of the four; and when one has acquired experience in the comparison of opalescence, it is perhaps also the most accurate.

RATIO OF SILVER TO BARIC CHLORIDE.

Fourth Series: Stas's Third Method.

No. of Exp.	Weight of Crystallized Baric Chloride.	Weight of Anhydrous Baric Chloride.	Weight of Silver taken.	Excess of Silver found.	Total Weight of Silver.	Ratio 2 Ag : $BaCl_2$ = 100 : x.	Atomic Weight of Barium.
	grams.	grams.	grams.	milligrams.	grams.		
42	7.63356	6.50022*	6.7346	0.4	6.7342	96.525	137.448
43	12.01793	[10.23365]	10.6067	4.4	10.6023	96.523	137.442
					Average	96.524	137.445

The Atomic Weight of Barium.

The data based upon the two more satisfactory ratios detailed in this paper have been grouped in seven series of determinations. In the first three series, including ten individual experiments upon the first ratio, the individual results are grouped together according to the condition of the baric chloride used as the starting point. This method of grouping was adopted because the analytical conditions were necessarily quite uniform, and the initial state of the salt was the most important variable. This problem having been solved satisfactorily, the accurate decision of the true end-point in the method of Gay Lussac remained the most important incidental question to be settled during the determination of the second ratio. Hence, the last four series were grouped according to the method of titration.

From the Ratio of Baric Chloride to Argentic Chloride.

Atomic Weight of Barium if O = 16.000.

I. Five experiments, $BaCl_2$ ignited in air = 137.428
II. Three experiments, $BaCl_2$ ignited in HCl = 137.446
III. Two experiments, $BaCl_2$ not ignited = 137.444
137.439

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* This specimen of baric chloride was dehydrated by ignition in a stream of hydrochloric acid. The specimen whose weight is recorded in brackets below it was not ignited; but the weight of the anhydrous salt was computed by means of the proportion 7.63356 : 6.50022 = 12.01793 : x.

From the Ratio of Baric Chloride to Silver.

I. Five experiments, Stas's second method = 137.419
II. Three experiments, first new method = 137.445
III. Four experiments, second new method = 137.449
IV. Two experiments, Stas's third method = 137.445
137.440

Before discussing these averages it may be well to recall the results obtained from baric bromide. These last results may be divided into two groups of two series each, the essential difference between the two series depending upon their relative accuracy.

From the Ratio of Baric Bromide to Argentic Bromide.

I. Experiments 3 to 12; Ba = 137.424
II. Experiments 13 to 19; Ba = 137.439
137.431

From the Ratio of Baric Bromide to Silver.

I. Experiments 3 to 12; Ba = 137.422
II. Experiments 13 to 19; Ba = 137.435
137.428

Total average of four groups **137.434**

The four groups, including eleven series and forty-nine individual results, are thus essentially unanimous in the verdict that the atomic weight of barium is between 137.42 and 137.45. Upon closer examination of details, it is apparent that some of the series are more trustworthy than others. In general, the first series of each group is considerably less reliable than the following ones, for obvious reasons. The first series of the first and second groups have the additional disadvantage of having been the victims of rather unsatisfactory methods. Since the most probable errors tend in any case to lower the observed atomic weight, the striking out of these lower results appears all the more allowable.

The more trustworthy results which remain may be averaged as follows: —

From the Ratio $BaCl_2 : 2\,AgCl$; $Ba = 137.445$
" " $BaCl_2 : Ag_2$; $Ba = 137.446$
" " $BaBr_2 : 2\,AgBr$; $Ba = 137.439$
" " $BaBr_2 : Ag_2$; $Ba = 137.435$
Average **137.441**

This average is after all but little different from the total mean of all the determinations, 137.434; and either average may be taken without serious error for the atomic weight of barium. Indeed, in the present state of chemistry, the third decimal place is of little or no importance in a large atomic weight, and the round number 137.44 is sufficient for the most exacting work.

An excellent proof of the purity of the materials and the accuracy of the work is to be found in the comparison of the weights of silver and argentic chloride. Omitting in each case the less accurate first series, we may repeat the following figures:

[II.] $2\,AgCl : BaCl_2 = 100 : x = 72.6563$
[III.] $2\,AgCl : BaCl_2 = 100 : x = 72.6555$
Average 72.6559

[II.] $2\,Ag : BaCl_2 = 100 : x = 96.524$
[III.] $2\,Ag : BaCl_2 = 100 : x = 96.526$
[IV.] $2\,Ag : BaCl_2 = 100 : x = 96.524$
Average 96.5247

Hence $Ag : AgCl = 72.6559 : 96.5247$
$= 107.930 : 143.387$

Therefore the atomic weight of chlorine is found to be 35.457, a quantity exactly identical with that found by Stas in a different way. A similar comparison of the weights of the silver and argentic bromide has been given already in the fifth column in the table on page 29 of Volume XXVIII. of these Proceedings.

It remains only to compare these figures with the older ones already described. Evidently all results for barium based upon the conversion of baric chloride into baric sulphate, as well as all results including water of crystallization, are worthy of no confidence. The incomplete knowledge regarding the method of Gay Lussac manifested by Marignac and Dumas in 1858 is quite enough to explain their unsatisfactory and discrepant results. We should expect to find the ratio of baric chloride to argentic chloride the most accurately determined of all the old ratios; and in fact Turner in 1829 obtained in this way a very good result (137.45). Upon the other hand, Marignac's single result by this method (137.14) was much too low. The description of his work is so superficial that a guess as to the reason for this discrepancy is out of place; nor is such a guess necessary, for a single experiment can carry with it no important weight.

The new result for the atomic weight of barium, reduced to the various standards in present use, is given below. As before, the mathematical statement of the "probable error" is omitted, because this error is so small as to be meaningless.

If Oxygen = 16.00. Barium = 137.44
" = 15.96. " = 137.10
" = 15.88. " = 136.41

III.

CONTRIBUTIONS FROM THE CRYPTOGAMIC LABORATORY OF HARVARD UNIVERSITY.

XXI.—NEW GENERA AND SPECIES OF LABOULBENIACEÆ, WITH A SYNOPSIS OF THE KNOWN SPECIES.

By Roland Thaxter.

Presented November 8, 1893.

In attempting some years since to obtain materials for a monograph of the Laboulbeniaceæ, the writer did not anticipate that a fifth preliminary paper would be reached before he felt in a position to publish a general account of the family; yet, however much the description of so large a number of new forms without proper figures is to be regretted, the delay in this respect seems fully justified by the essential data which have been obtained during the past two years. It cannot be doubted that the number of existing forms greatly exceeds the total already known, but it seems safe to assume that the basis of knowledge now available is sufficient to illustrate, at least in a general way, the more important characteristics of the group from a morphological as well as a systematic point of view. The promised monograph will therefore be published as soon as the necessarily numerous plates can be completed; and since a sixth preliminary paper will, if possible, be avoided, a summary of the known genera and species is appended for convenience of reference, together with a very brief note concerning certain matters relating to the general morphology and development of the group.

The writer's observations, based upon an examination of several thousand specimens illustrating more than a hundred species and more than twenty genera, appear to warrant the following conclusions.

The Laboulbeniaceæ, while showing no signs of any non-sexual mode of reproduction, are characterized by a well marked sexual type, closely resembling that of the simpler Florideæ. They are ascomycetous fungi, producing usually four, sometimes eight spores in asci which arise by a peculiar process of budding from ascogenic cells, of which there may be from one to four, usually distinct and eventually free within the cavity of the perithecium.

The ascogenic cells are developed from a carpogonium consisting of a single axile cell which is fertilized by non-motile male bodies (antherozoids) through the agency of a more or less highly developed trichogyne from which it is separated by a second axile cell. After fertilization the carpogenic cell divides by transverse septa (in ascertained cases) into three cells, the middle cell becoming either directly an ascogenic cell or dividing into from two to four such cells, while the other two supporting cells eventually disappear.

The trichogyne varies from a simple vesicular receptive prominence, or short filament, to a copiously branched and highly developed organ, the numerous free receptive tips of which may be coiled in close and regular spirals. The trichogyne, the insertion of which is usually terminal, disappears immediately after fertilization is accomplished, however highly it may be developed, its insertion becoming lateral by the further development of the perithecium.

The antherozoids appear to originate in two genera exogenously from special branches. In all other genera they are produced endogenously in antheridia, the form and position of which vary in the different genera. The antheridia are either single specialized cells, which may be more or less irregularly disposed or characteristically grouped, or may consist of more highly developed multicellular bodies. In either case the antherozoids are discharged through a terminal pore in the form of rod-like or nearly spherical masses of naked protoplasm.

The sexes are commonly both present on the same individual, usually so placed that self-fertilization is readily accomplished, or may be completely separated on specialized individuals. In the latter case of the members of any given spore pair formed in an ascus and discharged simultaneously from the perithecium one produces a male, while the other produces a female individual, thus insuring the juxtaposition of the sexes at the new point of infection.

The spores which may be formed in pairs within the asci, or less definitely disposed, are of one general type, fusiform in shape and divided by a more or less well defined septum into two parts, the relative position of which in formation is reversed in development, the segment which is basal in relation to its position in the ascus becoming distal in its relation to the growing plant resulting from its germination. A well defined gelatinous envelope surrounds the spore when mature, and develops with the growing plant to form a sac-like covering continuous over all its parts with the exception of the pore of the perithecium and certain portions of the sexual organs, its formation being independent of the cell divisions which take place inside it.

The new forms described below include a portion of the novelties collected during the past summer, and are distributed among the genera as follows: Ceratomyces, two species; Teratomyces, two species; Cantharomyces, one species; Peyritschiella, one species; Dichomyces, two species; Heimatomyces, one species; Dimorphomyces, one species; while the four new genera described, Sphaleromyces, Moschomyces, Camptomyces, and Compsomyces, include each a single species. As in previous instances, the writer is indebted to the kindness of Mr. Henshaw for the determinations of hosts.

CERATOMYCES HUMILIS, nov. sp.

Hyaline becoming faintly tinged with brownish. Perithecium rather narrow, without any appendage, the apex blunt or nearly truncate, its cell rows composed of not more than seven cells. Receptacle composed of from two to five superposed squarish cells. Appendage consisting of six to twelve superposed cells, the series tapering distally and producing irregularly from its inner face branches which may in turn be several times branched and may reach a length twice that of the perithecium. Spores 22 × 3 μ. Perithecia 100 × 25 μ. Total length to tip of perithecium 150–185 μ. Longest branches of appendage 180 μ.

On legs and at the edges of the elytra of *Berosus striatus* Say. Kittery Point, Maine.

A somewhat insignificant species allied to *C. contortus*, from which it is easily distinguished by its small size and by the absence of any appendage near the tip of the perithecium. It occurs more frequently between the terminal claws of the middle pair of legs, but is rarely found on the elytra. In two specimens the perithecia have become distinctly tinged with brown, but as a rule the whole plant is hyaline.

CERATOMYCES TERRESTRIS, nov. sp.

Nearly hyaline with black or dark brown suffusions. Perithecia large, slightly inflated, tapering to a bluntly rounded or truncate apex from which the sharply pointed lips project: the wall of the perithecium consisting of four series of about twelve cells each, its base formed from three small cells, below which a single similar small cell connects it with the receptacle. Receptacle consisting of three small superposed squarish cells, the upper of which gives rise to the perithecium and the appendage. The appendage, consisting of six or more superposed flattened cells becoming externally suffused with blackish brown or black (the suffusion sometimes involving the whole series as well as the entire receptacle with the exception of its basal cell), bearing on its inner side numerous hyaline branches which may in turn be once or twice branched, the lower arising from a series of small cells which may extend across the base of the perithecium on one side. Spores 15 × 2.5–3 μ. Perithecium 75–90 × 22–29 μ. Receptacle 25 μ long. Total length to tip of perithecium 100–140 μ, to tip of main appendage 45–65 μ. Longest branches of appendage 75 μ.

On *Lathrobium punctulatum* Lec. Kittery Point, Maine.

This minute and curious species is chiefly interesting from the fact that it is a terrestrial form in a typically aquatic genus, of which, however, it seems to possess all the essential characters. Unlike most of its congeners, it is among the smallest of all the Laboulbeniaceæ, and is very readily overlooked.

SPHALEROMYCES, nov. gen.

Receptacle consisting of two superposed cells, the distal bearing the appendage laterally, and the stalk cell of the perithecium terminally. Perithecium asymmetrical, the apex somewhat pointed; separated from its short stalk cell by three basal cells. Appendage clearly distinguished from the receptacle, composed of a basal cell bearing a series of superposed cells, each giving rise from its inner upper angle to a single short septate branch which may bear flask-shaped antheridia. Spores once septate involved in mucus. Asci arising in a double row from a single large ascogenic cell.

Sphaleromyces Lathrobii, nov. sp.

Wholly hyaline or faintly yellowish. Perithecium rather slender, slightly inflated towards the base, tapering to the somewhat pointed apex which is bent inwards; the dividing lines between the wall cells indicated by successive ridges, the distal more prominent: the short stalk cell, separated from the perithecium by three additional cells. Receptacle consisting of two obliquely superposed cells, the upper bearing the stalk cell of the perithecium distally and the basal cell of the appendage laterally. Appendage borne on a large basal cell connected on its inner side with the distal cell of the receptacle and a portion of the stalk cell of the perithecium, its exterior wall usually much thickened so as to form a more or less distinct rounded prominence at the base of the appendage proper, which consists of a series of four or five obliquely superposed cells diminishing in size towards its apex, from each of which arises on the inner side a single branch; the branches directed obliquely upwards and forming a single series, septate, cylindrical, simple or bearing near their tips single short branches or flask-shaped cells. Spores 35 × 3–3.5 μ. Perithecia 100 × 22 μ — 140 × 36 μ. Total length to tip of perithecium 160–240 μ. Total length to tip of distal branch of appendage 110–166 μ. Receptacle 38–45 μ long.

On *Lathrobium nitidulum* Lec. and *L. punctulatum* Lec. Kittery Point, Maine.

The writer is unable to refer this perplexing yet distinct form to any of the described genera. In general appearance it resembles Stigmatomyces, to which it might be referred if the successive cells of the appendage gave rise directly to antheridia. The resemblance, however, is superficial, since the character of the appendage is essentially different. Among the remaining genera it might perhaps be compared with the more simple type of Ceratomyces, from which the clear differentiation of its appendage and the structure of its perithecium as well as the character of its antheridia would seem to distinguish it. Specimens from *L. nitidulum* are distinctly smaller than those on the larger host. The species seems to be a rare one, and inhabits the legs and abdomen of its host, where, owing to its small size and pale color, it is detected with difficulty.

COMPSOMYCES, nov. gen.

Receptacle consisting of two superposed cells, the distal bearing from its extremity a cluster of appendages and one or more stalked perithecia. Appendages sterile or fertile, simple or branched, septate, the fertile ones bearing one or more single one-celled antheridia separated by oblique partitions from the extremities of successive cells composing the main axis of the appendage. Perithecia symmetrical, conical, borne on two superposed stalk cells and three small basal cells, the basal stalk cell producing from its distal end a simple sterile appendage. Asci 8-spored. Spores once septate.

COMPSOMYCES VERTICILLATUS.

Cantharomyces verticillatus Thaxter.

This species was found not uncommonly on *Sunius longiusculus* at Kittery Point, Me., during the past summer, and an examination of new material shows conclusively that it is generically distinct from Cantharomyces as emended in a previous paper. Its antheridia are not compound as in that genus, but simple, more or less flask-shaped and produced in a fashion more closely resembling that of certain species of Laboulbenia. The trichogyne is remarkably developed, copiously and regularly several times branched, the free receptive tips being coiled in close and regular spirals.

MOSCHOMYCES, nov. gen.

Receptacle composed of a sucker-like compacted mass of parenchymatous cells penetrating the softer chitin of the host and giving rise above to numerous free cells from the distal ends of which are produced solitary stalked perithecia and appendages. Perithecium very large, subconical, pointed, the apex symmetrical, borne on two simple superposed stalk cells followed by three small basal cells; the basal stalk cell bearing from its distal end a single simple sterile appendage. Appendages septate, sparingly branched or simple, the fertile ones stouter, bearing one-celled antheridia laterally. Asci subcylindrical, eight-spored, arising in great numbers and in many rows from a single ascogenic cell or centre. Spores minute, acicular, once septate.

MOSCHOMYCES INSIGNIS, nov. sp.

Perithecia pale straw-colored, becoming tinged with brown, the lower portion slightly inflated and abruptly contracted at the base, the distal portion subconical, sometimes slightly bent to one side, the apex narrow, truncate, symmetrical, the surface marked by two series of ridges extending around the perithecium, each series composed of four distinct and prominent ridges placed somewhat irregularly and indicating the lines of separation between the middle and the upper and lower series of cells which form the walls of the main body of the perithecium: basal cells of the perithecium small, three in number, not distinguished from it but somewhat abruptly distinguished from the distal stalk cell, which is long, subcylindrical, sometimes inflated and curved; the basal stalk cell usually shorter and smaller, bearing distally a single slender simple rather closely septate tapering appendage, usually about as long as the distal stalk cell. The appendages, which together with the single stalked perithecia spring in groups of three or four from the distal ends of large cylindrical cells projecting from the sucker-like receptacle (more rarely arising from the latter directly), are simple or once branched, either sterile or producing the supposed antheridia on short branches near their extremities. Spores very minute, acicular, septate near the middle, 12 × 3 μ. Asci subcylindrical, 40–45 × 7.5 μ, eight-spored, the spores sub-distichous. Perithecia 225–290 × 55–75 μ, the stalk cells (longest) 425 μ, average 375 × 25 μ. Appendages 175–375 μ long. Breadth of sucker-like receptacle 75 μ.

On *Sunius prolixus* Er. Waverly, Mass.

This form, which is among the most remarkable thus far discovered, differs from all other genera in the structure of its attachment to the host. It inhabits only the softer chitinous membranes, beneath the elytra and at the bases of the legs or between the segments, which it perforates by the intrusion of its sucker-like base. It is more nearly allied to Compsomyces than to any other known genus. The minute spores are formed in enormous numbers and discharged in masses. The asci arise from a single centre, apparently a single cell, in numerous rows, and are distinctly eight-spored.

TERATOMYCES Thaxter.

Three additional species of this genus, two of which are described below, represent a well marked type adhering closely to that previously described. The discharge of antherozoids has been observed in fresh material and the antheridia prove to be the beak-like cells characteristic of all the species. The trichogyne has been observed in two species in which it differs widely; in the one case appearing as a branched organ very similar to the ordinary terminal branches of the appendages, while in the other it is highly developed with peculiarly modified receptive tips.

Teratomyces Actobii, nov. sp.

Perithecia one to several, reddish brown distinctly inflated towards the base, the distal portion symmetrically conical, tapering to a blunt apex; borne on a single short stalk cell not exceeding the appendages in length followed by three unusually large basal cells disposed as in *T. mirificus.* Receptacle short nearly symmetrical tinged with brownish or nearly hyaline, consisting of three superposed cells, the basal small and narrow, the sub-basal squarish, the distal large, rounded and followed by the circular series of small cells from which arise the numerous appendages which in general resemble those of *T. mirificus* though proportionately stouter and more intricately branched. Spores 26 × 3.7 μ. Perithecia 120–137 × 37 μ. Stalk cells 75–100 μ. Longest appendages 150 μ. Three basal cells of receptacle 37 × 22 μ.

On *Actobius nanus* Horn. Kittery Point, Maine.

This species occurred with the next on the legs of its host. It differs from *T. mirificus* in the form of its perithecia, which are subconical, as well as by its hyaline or nearly hyaline symmetrical receptacle. The short stalk cell and large basal cells of its perithecia serve also to distinguish it.

TERATOMYCES BREVICAULIS, nov. sp.

Perithecia several, purplish brown, long, slender, straight or slightly curved, cylindrical or slightly inflated near the middle, tapering abruptly to the almost truncate apex, much longer than the stalk and basal cells together, the latter concolorous with the perithecium, the stalk cell nearly hyaline. Receptacle nearly symmetrical, black and quite opaque, except the partly translucent basal cell; above the opaque portion expanding abruptly to form the broad distal portion from the numerous small cells of which arise, around the edge, the circle of crowded appendages which surround the perithecia. Larger appendages faintly tinged with brownish purple, consisting of a rather short basal cell bearing a short series of superposed external branches, the uppermost consisting of a large, long basal cell curved and somewhat inflated distally, where it bears externally a series of two to five secondary branches similarly shaped which may in turn be similarly branched, the ultimate branchlets bluntly pointed with numerous slightly oblique septa or terminating in long beak-like cells (antheridia). Spores 33 × 4 μ. Perithecia 110–120 × 23 μ. Stalk cells 50 × 15 μ. Receptacle 85 × 50 μ. Longest appendages 100 μ.

On *Actobius nanus* Horn. Kittery Point, Maine.

This curious species is quite distinct from that with which it was associated on the same host, and differs in the form of its perithecia and appendages as well as the peculiar and abrupt distal expansion of its receptacle. Both of the types, which occurred at the tip of the abdomen of the host, have three perithecia.

Cantharomyces pusillus, nov. sp.

Perithecium becoming reddish brown, inflated just above the base, the distal portion conical tapering to a blunt symmetrical apex, borne on a rather short narrow stalk cell bent towards the appendage and separated from the perithecium by three small subtriangular basal cells. Receptacle consisting of a very small basal and a much larger rounded sub-basal cell, more or less suffused with brown, which gives rise to the stalk cell of the perithecium and the appendage. Antheridial appendage consisting of a large squarish basal cell followed by the antheridium proper, which is primarily a large squarish cell, its outer half or more becoming divided by anastomosing septa into numerous small cells, the inner portion also showing a division into two or three larger cells; the whole bearing terminally a series of usually three superposed flattened cells strongly constricted at the septa and giving rise distally to from one to three simple cylindrical nearly hyaline sparingly septate branches, usually exceeding the perithecium in length. Spores 18 × 2 μ. Perithecia 22–26 × 30–55 μ. Total length to tip of perithecia 80–85 μ, to tip of appendages 90–120 μ.

On *Trogophlœus* sp. York, Maine; Waverly, Mass.

This species is perhaps the smallest of the known forms of Laboulbeniaceæ, and is somewhat difficult to discover and remove from the legs or elytra of its host, where, however, it is not rarely found. Owing to its minute size the detailed structure of the antheridium was not plainly made out, neither was any discharge of antherozoids noticed. It corresponds so closely, however, to the structure characteristic of the genus as emended, that there can be little doubt of the correctness of its generic reference.

CAMPTOMYCES, nov. gen.

Receptacle consisting of two superposed cells, the upper bearing the short-stalked perithecium laterally and the antheridial appendage terminally. Perithecium narrow, with coarse-lipped asymmetrical apex. Appendage consisting of a single large basal cell bearing the antheridium terminally. Antheridium multicellular, subconical, with a prominent terminal pore for the discharge of the numerous roundish antherozoids. Trichogyne developed as a small vesicular prominence above a permanent ear-like appendage which arises laterally from the young perithecium. Ascogenic cells two in number.

CAMPTOMYCES MELANOPUS, nov. sp.

Perithecium tinged with brownish, slightly inflated towards the base, its distal half narrow, tapering gradually to the rounded apex below which on one side is a rounded projection; borne on a large subtriangular stalk cell surmounted by three smaller basal cells. Receptacle narrowly funnel-shaped, tapering to a pointed base and consisting of a large basal cell, slightly translucent near its lower extremity, but otherwise becoming wholly opaque, followed by a flattened sub-basal cell from which the mature perithecium with its stalk projects nearly at right angles to the long axis of the receptacle, while distally it bears the appendage. Appendage bearing terminally the subconical slightly asymmetrical antheridium. Spores about 25 × 3.5 μ. Perithecium 130–150 × 30–33 μ. Total length to tip of antheridium 110–125 μ. Greatest width 25 μ. Antheridium 25 × 16 μ.

On *Sunius prolixus* Er. Waverly, Mass., and York, Maine.

This curious form affords an additional example of a highly developed type of antheridium which has neither the peculiar honeycomb-like appearance of Cantharomyces and Haplomyces nor the more simple type of Peyritschiella and its allies, Dichomyces and Heimatomyces. It is distinguished from the two genera first named by having a strictly terminal pore without appendages of any kind. It shows a clearly defined cavity within which the spermatia are formed which is surrounded on three sides (wholly near its base) by several rows of cells not symmetrically disposed. The species occurs rather rarely on the abdomen of its host, the perithecia being usually directed forward.

PEYRITSCHIELLA GEMINATA, nov. sp.

Hyaline. Receptacle asymmetrical, consisting of a single basal cell followed by three successive more or less definite transverse rows of cells. The lowest of these rows is the most variable and irregular, consisting of from two to four cells, one of which, larger than the rest, is an axile cell continuing the basal cell directly, while the remaining one to three cells are cut off from it on one side, each successive cell smaller and placed higher in the series, the outermost and uppermost bearing one of the sterile appendages characteristic of the genus. The second row also consists of a larger axile cell, which is free for a short distance on one side, and on both sides of which are cut off, as in the first row, from two to four cells, the smaller uppermost ones on both sides giving rise to from one to three appendages according to the number of the cells. The upper row is either symmetrical or asymmetrical according as it gives rise to two or to only one perithecium. In the first instance it consists of an axile cell, above which are produced two sterile appendages, and a variable number of cells cut off laterally as in the lower rows, but nearly symmetrical in size and shape, the outermost bearing sterile appendages. If one perithecium only is produced the row is asymmetrical and a greater number of appendages appear on one side of the perithecium than on the other. Perithecia very slightly inflated near the base, tapering abruptly but slightly to the spreading apex, which is four-lobed, the lobes rounded, large, and prominent. Spores about 37 × 3.7 μ. Perithecia 75–80 × 18–22 μ. Total length to tip of perithecia 220–260 μ (150 μ in specimens from the smaller host).

On *Pterostichus luctuosus* Dej. and *P. patruelis* Dej. Kittery Point, Maine.

Unlike the other species, this form not infrequently produces two perithecia, the arrangement of its distal cells in such cases closely resembling that of Dichomyces. The main body of the receptacle is however asymmetrical, and the minute antheridium as far as can be ascertained from the material obtained occurs only on one side. It forms nevertheless an additional point of connection between the two genera, which may ultimately have to be united, despite the extreme differences between the type species in either case.

DICHOMYCES INFECTUS, nov. sp.

Receptacle consisting of a short basal cell succeeded by an axile cell placed vertically, on either side of which a series of three obliquely superposed cells forms a blackened border. The remainder of the receptacle consisting of two successive transverse symmetrical rows of cells, the lower row made up of three central and several smaller external cells terminating on either side in a short blunt projection below the prominent antheridia, beside which arise single sterile appendages. The distal row is composed of seven cells, the external cells on either side not extending beyond the bases of the perithecia and destitute of appendages; two appendages arise between the perithecia, one on either side. Perithecia two, closely approximated, arising from single broad flattened cells, short and stout, tapering slightly towards the subtruncate apex, which is destitute of papillæ or appendages. Perithecia 66 × 22 μ. Receptacle 60 × 40 μ.

On *Xantholinus obsidarius* Melsh. Waverly, Massachusetts.

Two specimens of this small form were found at the tip of the abdomen of its host.

DICHOMYCES INÆQUALIS, nov. sp.

Receptacle as in *D. furciferus*, its fork-like projections prominent and indistinctly septate, the distal row of cells bearing a single perithecium but symmetrical except that the submedian cell, above which a second perithecium arises in *D. furciferus*, is much reduced in size. Appendages ten to twelve, one at the base of each antheridium, two above the median cell of the distal row, and three to four borne one from each of the three to four cells of the distal row external to the submedian cells, all arising as in *D. furciferus*. Perithecia large, slightly inflated towards the base or subcylindrical, tapering abruptly at the extremity to a subtruncate apex destitute of appendages. Spores 26 × 3.5 μ. Perithecia 100 × 25 μ. Receptacle, length to base of perithecium 92 μ ; length to tips of lateral forks 110–130 μ ; greatest breadth 50–60 μ. Total length to tip of perithecium 180–190 μ.

On *Philonthus debilis* Grav. Kittery Point, Maine, and Waverly, Massachusetts.

This species occurs sometimes in company with *D. furciferus* on the abdomen, more rarely on the legs and thorax of its host. It is at once distinguished by its solitary perithecium, which is destitute of the ear-like appendages peculiar to the last named species. The presence of a single perithecium necessitates a modification of the generic diagnosis in this respect, but despite the absence of the usual pair, which seems to be invariable, the bilateral symmetry of the plant is otherwise maintained. More abundant material of *D. furciferus* shows the presence of an appendage placed beside each antheridium, a character also found in both the new species just described.

HEIMATOMYCES AURANTIACUS, nov. sp.

Pale straw-colored, the cell contents including numerous rather bright orange granules or oil globules. Perithecium, exceeding the tip of the receptacle by from one fifth to one quarter of its length, small, slender, the tip usually curved outwards, the lips rather prominent. Receptacle slender, the basal cell suffused with brown below, the sub-basal cell small and flat, the two succeeding cells elongate, the outer shorter and continued above by an unusually large basal cell of the perithecium : distal portion of the receptacle as in *H. borealis* composed of three cells, the two lower very long and narrow, subtriangular, obliquely superposed, their lower extremities nearly touching the sub-basal cell. Perithecium 50 × 14–15 μ. Total length to tip of receptacle 85–90 μ; to tip of perithecium 100–110 μ. Greatest breadth 22 μ.

On *Desmopachria convexa* Aube. Kittery Point, Maine.

A rare species occurring on the right elytron near the middle of its distal half. Distinguished from *H. orientalis*, which occurs also very rarely on the same host, and *H. Bidessarius*, by its slender form and orange color as well as the details of its structure. It is a very delicate species, seldom found in good condition.

DIMORPHOMYCES MUTICUS, nov. sp.

Male individual as in *D. denticulatus*, the basal cell more or less suffused with blackish.

Female individual. Receptacle consisting of three superposed cells, the basal cell becoming subtriangular through the successive separation, from its upper angles on either side, of a transverse series of cells, each of which gives rise to a single perithecium or a single sterile appendage in regular succession. Appendages simple, single, septate, seldom equalling the perithecia in length. Perithecia one to six, becoming slightly brownish and curved, subclavate, notched on one side below the truncate or bluntly rounded asymmetrical apex and destitute of any tooth-like outgrowth. Spores 22–25 × 3 μ. Perithecia 75–90 × 15 μ. Total length to tip of perithecia 90–130 μ.

On *Falagria dissecta* Er. Maine and Massachusetts.

This species corresponds essentially in structure with *D. denticulatus*, from which it is readily distinguished by its perithecia, which are larger and without the peculiar tooth-like appendage of the last named species. The male individuals can hardly be distinguished except for the suffusion of the basal cell.

In the following synopsis the genus Hesperomyces Thaxter has been dropped as synonymous with Stigmatomyces, and all published species have been included, without regard to certain probable cases of synonymy. The arrangement suggested is entirely provisional, yet indicates in a general way the natural sequence of the genera.

I. ANTHEROZOIDS ENDOGENOUS.

A. Antheridia composed of several Cells.

§ Diœcious . . . . Dimorphomyces
1. On *Falagria dissecta* Er. . . . . *denticulatus.*
2. On *Falagria dissecta* Er. . . . . *muticus.*

§§ Monœcious.

* Antheridium borne on an appendage free from the receptacle.

a. Antheridium lateral below a terminal branch of the appendage . . . . Cantharomyces
1. On *Bledius assimilis* . . . . *Bledii.*
2. On *Bledius armatus* Er. . . . . *occidentalis.*
3. On *Trogophlœus* sp. . . . . *pusillus.*

b. Antheridium terminal tipped by a spine-like process. Haplomyces
1. On *Bledius ornatus* Lec. . . . . *californicus.*
2. On *Bledius rubiginosus* Er. . . . . *texanus.*
3. On *Bledius emarginatus* Say . . . . *virginianus.*

c. Antheridium terminal with a prominent apical pore. Camptomyces
1. On *Sunius prolixus* Er. . . . . *melanopus.*

** Antheridium united to the body of the receptacle from which its pointed apex projects.

a. Perithecia terminal, free from the asymmetrical receptacle. Terrestrial . . . . Peyritschiella
1. On *Platynus cincticollis* (Say) . . . . *curvata.*
2. On *Platynus cincticollis* (Say) . . . . *minima.*
3. On *Plerostichus luctuosus* Dej. and *P. patruelis* Dej. . . . . *geminata.*
4. On *Philonthus debilis* Grav. . . . . *nigrescens.*

b. Perithecia terminal, free from the symmetrical receptacle. Terrestrial . . . . Dichomyces
1. On *Philonthus debilis* Grav. . . . . *furciferus.*
2. On *Philonthus debilis* Grav. . . . . *inæqualis.*
3. On *Xantholinus obsidarius* Melsh. . . . . . *infectus.*

c. Perithecium wholly or partly united to the asymmetrical receptacle on one side. Aquatic Heimatomyces
1. On *Haliplus ruficollis* DeG. and *Cnemidotus muticus* Lec. . . . . *Halipli.*

2. On *Laccophilus maculosus* Germ., *L. hyalinus* Dej., and *L. minutus* Sturm . . . . . . *paradoxus.*
3. On *Laccophilus maculosus* Germ. . . . *appendiculatus.*
4. On *Laccophilus hyalinus* Dej. and *L. minutus* Sturm . . . . *melanurus.*
5. On *Laccophilus maculosus* Germ. *Hydroporus spurius* Lec. and *sp. indet.* . . . *marginatus.*
6. On *Laccophilus maculosus* Germ. and *Hydroporus spurius* Lec. . . . . *rhyncostoma.*
7. On *Laccophilus maculosus* Germ. . . . *lichanophorus.*
8. On *Laccophilus maculosus* Germ. and *Hydroporus spurius* Lec. . . . . *uncinatus.*
9. On *Laccophilus maculosus* Germ. . . . . . *hyalinus.*
10. On *Laccophilus maculosus* Germ. and *Hydroporus sp.* . . . . *affinis.*
11. On *Laccophilus maculosus* Germ., *Hydroporus spurius* Lec., and *gen. indet.* . . . . *simplex.*
12. On *Bidessus granarius* Aube . . . . . *Bidessarius.*
13. On *Desmopachria convexa* Aube . . . . . . *borealis.*
14. On *Desmopachria convexa* Aube . . . . *aurantiacus.*

B. ANTHERIDIA COMPOSED OF SINGLE CELLS.

Diœcious . . . . AMORPHOMYCES

1. On *Falagria dissecta* Er. . . . . *Falagriæ.*
2. On *Bledius basalis* Lec. . . . . *floridanus.*

§ Monœcious.

* Antheridia borne in definite series on the appendages.

γ Antheridia springing directly from successive cells of the appendage.

a. Appendage solitary, bearing the antheridia in several vertical series . . . . . . HELMINTHOPHANA

1. On *Nycteribia Dufourii* . . . . *Nycteribiæ.*

b. Appendage solitary, bearing the antheridia in a single vertical series . . . . STIGMATOMYCES

1. On *Drosophila nigricornis* Loew. . . . . *entomophila.*
2. On *Musca domestica* L. . . . . *Baeri.*
3. On *Chilocorus bivulnerus* Muls. . . . . *virescens.*

c. Appendages numerous, arising directly from the receptacle, bearing the antheridia in a single vertical series . . . . IDIOMYCES

1. On *Deleaster dichrous* Grav. . . . . *Peyritschii.*

$\gamma\gamma$ Antheridia borne on branches of the appendages.

d. Appendages several, the antheridia borne on lateral branches in a single vertical series . . Corethromyces

1. On *Cryptobium pallipes* Grav. and *C. bicolor* Grav. *Cryptobii.*
2. On *Lathrobium nitidulum* Lec. . . . . *setigerus.*
3. On *Lathrobium jacobinum* Lec. and *L. collare* Er. *jacobinus.*

e. Appendage single, with terminal sterile branches; antheridia borne below its successive septa as lateral branches, often branched or irregular Rhadinomyces

1. On *Lathrobium nitidulum* Lec. and *L. punctulatum* Lec. . . . . *cristatus.*
2. On *Lathrobium fulvipenne* Grav., *L. punctulatum* Lec., and *L. angulare* Lec. . . . . *pallidus.*

** Antheridia not borne in any definite series on the appendage.

a. Receptacle of two superposed cells, the upper bearing several appendages and one or more stalked perithecia . . . . Compsomyces

1. On *Sunius longiusculus* Mann. . . . . . . *verticillatus.*

b. Receptacle closely multicellular, bearing numerous vertical cells from which arise terminally several appendages and solitary stalked perithecia Moschomyces

1. On *Sunius prolixus* Er. . . . . *insignis.*

c. Receptacle typically nine-celled; the appendages two or more, terminal, the inner fertile . . . Laboulbenia

1. On *Anchomenus viduus* Pz., *A. albipes*, and *Platynus extensicollis* Say . . . . *anceps.*
2. On *Harpalus pennsylvanicus* DeG. . . . . . . *arcuata.*
3. On *Antennophorus caput-carabus* . . . . . . *armillaris.*
4. On *Acrogenys hirsuta* Maclean . . . . . *australiensis.*
5. On *Brachinus mexicanus* Dej. and *spp. indet.* . *Brachini*
6. On *Patrobus longicornis* Say and *P. tenuis* Lec. . *brachiata.*
7. On *Casnonia pennsylvanica* Dej. . . . . . . *Casnoniæ.*
8. On *Catoscopus guatemalensis* Bates . . . . . *Catoscopi.*
9. On *Clivina dentifemorata* Putz. . . . . . . *Clivinæ.*
10. On *Bembidium spp. indet.* . . . . *compacta.*
11. On *Anisodactylus baltimorensis* Say . . . . . *compressa.*
12. On *Harpalus pennsylvanicus* DeG. . . . . . *conferta.*
13. On *Platynus extensicollis* Say . . . . *contorta.*
14. On *Coptodera Championi* Bates . . . . . . *Coptoderæ.*

15. On *Pæderus littorarius* Grav., *P. obliteratus* Lec., *P. ruficollis* Fabr., and *sp. indet.*	*cristata.*
16. On *Bembidium bimaculatum* Kirby	*curtipes.*
17. On *Harpalus pennsylvanicus* DeG.	*elegans.*
18. On *Platynus cincticollis* (Say)	*elongata.*
19. On *Chlænius æneocephalus* Dej., *C. Chrysocephalus* Rossi, *Callistus lunatus* Fabr., and *Aptinus mutilatus* Fabr.	*europæa.*
20. On *Chlænius vestitus* F.	*fasciculata.*
21. On *Anisodactylus Harrisii* Lec., *A. nigerrimus* Dej., and *A. interpunctatus* Kirby	*filifera.*
22. On *Bembidium lunatum* Duft., *Anchomenus albipes* F., and *A. marginatus* L.	*flagellata.*
23. On *Platynus cincticollis* (Say)	*fumosa.*
24. On *Galerita janus* Fabr., *G. mexicana* Dej., *G. atripes* Lec., and *sp. indet.*	*Galeritæ.*
25. On *Platynus extensicollis* Say	*gibberosa.*
26. On *Gyretes sericeus* Lab., *G. compressus* Lec., and *G. sinuatus* Lec.	*Guerinii.*
27. On *Gyrinus fraternus* Coup., *G. affinis* Aube, *G. aralis* Say, *G. confinis* Lec., *G. consobrinus* Lec., *G. plicifer* Lec., *G. ventralis* Kirby, *G. urinator* Illig., and *spp. indet.*	*Gyrinidarum.*
28. On *Harpalus pennsylvanicus* DeG.	*Harpali.*
29. On *Bradycellus rupestris* Say	*inflata.*
30. On *Galerita leptodera* Chaud.	*longicollis.*
31. On *Bembidium varium* Oliv. and *spp. indet.*	*luxurians.*
32. On *Galerita mexicana* Chaud., *G. nigra* Chev., and *G. æquinoctialis* Chaud.	*mexicana.*
33. On *Calleida pallidipennis* Chaud.	*minima.*
34. On *Morio georgiæ* Pal.	*Morionis.*
35. On *Nebria pallipes* Say, *N. Sahlbergi* Fisch, *N. Gregaria* Fisch, *N. Brunnea* Duft., and *N. Villæ* Dej.	*Nebriæ.*
36. On *Pachytelis mexicanus* Chaud.	*Pachytelis.*
37. On *Panagæus crucigerus* Say, and *P. fasciatus* Say	*Panagæi.*
38. On *Platynus extensicollis* Say. *P. æruginosus* Dej., and *sp. indet.*	*parvula*
39. On *Platynus melanarius* Dej., *P. ruficornis* Lec., and P. *extensicollis* Say	*paupercula.*

40.	On *Bembidium spp. indet.*	*pedicellata.*
41.	On *Pheropsophus æquinoctialis* Linn., *P. marginatus* Dej., and *spp. indet.*	*Pheropsophi.*
42.	On *Philonthus debilis* Grav., *P. cunctans* Horn, *P. micans* Grav., *P. æqualis* Horn, *P. californicus* Mann., and *spp. indet.*	*Philonthi.*
43.	On *Olisthopus parmatus* Say, *Stenolophus limbalis* Lec., *S. fuliginosus* Dej., *Badister maculatus* Lec., *Harpalus pleuriticus* Kirby, *Agonoderus pallipes* Fabr., and *gen. indet.*	*polyphaga.*
44.	On *Eudema tropicum* Hope, *Chlænius auricollis* Gory., and *Dolichus ? sp.*	*proliferans.*
45.	On *Pterostichus adoxus* Say, *P. luctuosus* Dej., *P. mancus* Lec., and *sp. indet.*	*Pterostichi.*
46.	On *Quedius vernilis* Lec.	*Quedii.*
47.	On *Platynus extensicollis* Say	*recta.*
48.	On *Brachinus crepitans* L., *B. explodens* Duft., *B. scolopeta* F., and (?) *Platynus cincticollis* Say	*Rougetii.*
49.	On *Platynus extensicollis* Say	*scelophila.*
50.	On *Schizogenius lineolatus* Say, and *S. ferrugineus* Putz.	*Schizogenii.*
51.	On *Anophthalmus Menetriesii* Motsch., *A. angustatus* Lec., and *A. Motschulskyi* Schm.	*subterranea.*
52.	On *Bembidium spp. indet.*	*truncata.*
53.	On *Stenolophus ochropezus* Say	*umbonata.*
54.	On *Anomoglossus pusillus* Say, *Chlænius æstivus* Say, *C. cumatilis* Lec., *C. cursor* Chev., *C. leucoscelis* Chaud., *C. floridanus* Horn, *C. pennsylvanicus* Say, *C. ruficaudis* Chaud., *C. sparsus* Lec., *C. texanus* Horn, *C. tricolor* Dej., *C. viridicollis* Reiche, *Omophron americanum* Dej., *O. nimbatum* F., and *spp. indet.*, *Patrobus longicornis* Say, *Platynus extensicollis* Say, *Pterostichus adoxus* Say, *P. luctuosus* Dej., *P. corvinus* Dej., *P. caudicollis* Say, and *Nebria pallipes* Say	*variabilis.*
55.	On *Bembidium littorale* Pz., *B. fasciolatum* Duft., *B. punctulatum* Drap., *B. lunatum* Duft., *B. obsoletum*, Dej., and *spp. indet.*	*vulgaris.*
56.	On *Crepidogaster bimaculata* Boh.	*zanzibarina.*

d. Receptacle two-celled, appendage single, bearing a series of branches superposed in a single row. SPHALEROMYCES.

1. On *Lathrobium nitidulum* Lec. and *L. punctulatum* Lec. . . . . *Lathrobii.*

e. Receptacle of numerous cells superposed in a single series giving rise directly on one side to fertile appendages, one or two perithecia, and sterile appendages in the order named . . . . CHÆTOMYCES

1. On *Pinophilus latipes* Er. . . . . *Pinophili.*

f. Receptacle consisting of a primary axis of several to many superposed cells and a secondary series of smaller cells irregularly placed and bearing numerous bristle-like appendages ACANTHOMYCES

1. On *Atranus pubescens* Dej. . . . . *lasiophora.*
2. On *Lathrobium longiusculum* Grav. and *sp. indet.* *Lathrobii.*
3. On *Lathrobium fulvipenne* Grav. . . . . . . *brevipes.*
4. On *Othius fulvipennis* Fab. . . . . *furcatus.*
5. On *Anophthalmus Bilimeki* Sturm. . . . . . . *hypogæus.*
6. On *Colpodes evanescens* Bates . . . . . . *longissimus.*

g. Receptacle multicellular, bearing distally two appendages on either side at the base of a stalked perithecium. . . THAXTERIA (Giard *nec* Sacc.)

1. On *Mormolyce phyllodes* Hagenb. . . . . . . *Kunkelii.*

h. Receptacle of three cells terminated by a horizontal series of numerous cells bearing a circle of appendages and one or more stalked perithecia surrounded by them . . . . TERATOMYCES

1. On *Acylophorus pronus* Er. . . . . *mirificus.*
2. On *Actobius nanus* Horn. . . . . *Actobii.*
3. On *Actobius nanus* Horn. . . . . *brevicaulis.*

II. ANTHEROZOIDS EXOGENOUS. Typically aquatic.

a. Receptacle of few or many superposed cells, running into the branch bearing appendage on one side and the wall of the perithecium on the other, the wall cells of the latter superposed in four many-celled rows . . . . CERATOMYCES

1. On *Tropisternus glaber* Hb. and *T. nimbatus* Say *mirabilis.*

2. On *Tropisternus glaber* Hb. . . . . *camptosporus.*
3. On *Hydrocombus fimbriatus* Melsh. and *Philhydrus cinctus* Say . . . . *rostratus.*
4. On *Tropisternus glaber* Hb. and *T. nimbatus* Say *filiformis.*
5. On *Tropisternus nimbatus* Say . . . . . . *minisculus.*
6. On *Lathrobium punctulatum* Lec. . . . . . . *terrestris.*
7. On *Berosus striatus* Say . . . . *contortus*
8. On *Berosus striatus* Say . . . . *furcatus.*
9. On *Berosus striatus* Say . . . . *humilis.*

b. Receptacle parenchymatously multicellular, numerous perithecia and appendages arising from its cup-shaped extremity . . . . . . ZODIOMYCES.

1. On *Hydrocombus lacustris* Lec., *H. fimbriatus* Melsh., and *gen. indet.* . . . . *vorticellarius.*

IV.

ON THE FORMATION OF VOLATILE COMPOUNDS OF ARSENIC FROM ARSENICAL WALL PAPERS.

By Charles Robert Sanger.

Received November 9, 1893.

In cases of chronic poisoning from arsenical wall papers, the form in which the arsenic leaves the paper has been a long disputed question. Certain well defined symptoms were easily attributable to the local irritant action of arsenical dust in the form of arsenious oxide, the copper greens, etc., and the extension of these symptoms to the digestive organs could be referred to the same cause. Yet, on the other hand, under conditions unfavorable to the separation of arsenical dust, as, for instance, where an arsenical paper underlay one that was perfectly free, cases of poisoning have been very frequent, and to explain them the formation of a gaseous or volatile arsenical compound was assumed.

Experiments to decide this point have been numerous since chronic arsenical poisoning by wall papers was recognized, but none of them until recently have been decisive, as they were with few exceptions carried on under unfavorable conditions and by methods that in point of exactness left much to be desired. Each side has had its adherents, the one asserting that chronic poisoning must be due entirely to dust, the other declaring that the cause lay in the absorption of an arsenical gas, or in the combined action of gas and dust. Many, not believing that the absorption of dust could alone lead to the numerous extreme or obscure cases that have been observed, have used the lack of proof of gas formation as an argument against the possibility of chronic poisoning from arsenical surroundings, although they admitted the local action of dust in certain cases. Further, those who denied the possibility of arsenical poisoning from wall paper under any circumstances considered their position strengthened by the failure to establish definitely the formation of a gaseous compound.

It was in this doubtful state that the question lay at the time when this investigation was begun, some seven years ago. My work was frequently interrupted and delayed, but about two years ago, I arrived rather reluctantly at results which seemed to show the improbability of the formation of an arsenical gas, though the possibility was as clear as ever. But the extension of bacteriological methods to the investigation has thrown a new light on the matter, and during the past year I have been able to satisfy myself of the correctness of the investigations which have shown that a volatile arsenical compound can be formed by action of certain moulds on organic matter containing arsenic. The nature of the compound is still unknown, and will require extended investigation before it is determined; but it certainly does not seem to be arseniuretted hydrogen, which was the compound commonly supposed to be formed.

HISTORICAL.

The danger from arsenical colors in living rooms seems to have been to some extent foreseen before cases of chronic poisoning actually arose, for an order of the Prussian government of January 12, 1815,* directed that the color should be rubbed from green walls when wet, and not when dry.

Gmelin,† in 1839, was the first to call attention to the danger from arsenical wall papers, and considered that the arsenic might be volatilized as some product of the fermentation of the organic matter with which it was mixed.

Riedel,‡ in 1844, says that "air can take up arsenic acid and hydrogen can form arseniuretted hydrogen."

Von Basedow,§ in 1846, considered that the arsenic might be liberated in the form of kakodyl. He gives some cases of poisoning in rooms painted with an arsenical green on a lime ground, and lays stress on the peculiar garlic odor which he notices. This he compares to the odor obtained by boiling arsenious oxide with acetic acid, and says it is similar to that which arises from stuffed birds. The occupants of the room noticed no such odor. Von Basedow notes that the arsenic decreases in the paper by decay, but no analyses are given in support of this assertion.

Krahmer,‖ in 1852, was the first to institute experiments to determine whether a volatile arsenical compound was liberated. He ridiculed the ideas of Riedel and v. Basedow, and considered that the arsenic could not even leave the walls as dust. His experiments were as follows. Four grams Neuwieder green were mixed with paste and lime taken from a damp part of a ground floor wall, and placed in a two-necked Woulff bottle. After 19 days he observed no odor of garlic, nor indeed could he observe any in the five years that elapsed before his results were published, during which time the mixture remained in the bottle. Five hundred litres of air were then drawn through the bottle for 21 days, the air first passing through alcoholic potassic hydroxide. The solution was then neutralized by hydrochloric acid, and, "on treatment with arsenic free zinc, gave no arsenic." We have here no idea of the delicacy or accuracy of the test used.

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* Krahmer, Deutsche Klinik, 1852, XLIII 481.

† Ref. by Eulenberg, *Die Lehre v. d. schädl. u. gift. Gasen*, 1865, p. 413, to Karlsruher Zeitung, November, 1839.

‡ Ref. by Krahmer, *loc. cit.*, to Ann. der Staatsarzneikunde, X. 407.

§ Preuss. Med. Zeitung, 1846, X. 43.

‖ *Loc. cit.*

Next, a solution of argentic nitrate was substituted for the potassic hydroxide and air drawn through for fifteen days. No change was observed in the silver solution, but it was not tested for arsenic. He then passed the air from the bottle for five days through a hard glass tube heated in two places and obtained no mirror of arsenic. He next thinks that the arsenic compound, if formed, should be mixed with hydrogen before absorption, and so places a hydrogen generator in front of the bottle. The hydrogen generated from 133 grams of zinc, after filtration by cotton wool, was passed through the bottle, then through a solution of alcoholic potassic hydroxide, then silver solution, and finally through the hot tube. He found no trace of arsenic in the solutions or in the tube. The test is not given. During the whole time there was no evidence of mould in the bottle.

Krahmer states that he had lived for eight years in a dry and airy room, the walls of which had received during that time three coats of Neuwieder green, probably five pounds at a time. He never felt any trouble from its presence. He repeatedly examined the dust for *color*, but never found any. To decide the question as to arsenic in the dust, he drew fifty litres of the air of the room through nitric acid, and added to it the dust that had fallen on a piece of paper during that time. The acid was then neutralized with sodic carbonate, evaporated, and the sodic nitrate melted. The residue was dissolved in water, filtered, and the filtrate tested with zinc and hydrochloric acid. He found no arsenic, which is hardly to be wondered at in the presence of so much nitric and nitrous acids. He could not find copper in the filtrate, but this was probably lost by ignition and filtration.

If Krahmer's experiments had been otherwise properly conducted, the method of examination for arsenic would alone have deprived them of value. Not finding, by his unskilful test, any arsenic in the dust, he concludes at once that arsenic cannot be liberated at all, and uses the result as an argument against the possibility of arsenical poisoning from wall papers.

Arnd,[*] in 1855, offers the following remarkable explanation: "Arseniates are decomposed by carbon dioxide, setting free arsenious oxide which is volatilized. By evaporation of the water from the paste, arsenical particles are carried off. Sulphide of arsenic on a lime ground is decomposed with evolution of arseniuretted hydrogen, as the lime takes away the sulphur, forming calcic sulphide."

Eulenberg[†] mentions the following experiment made in 1857 by Halley and Williams, but I can find no account of it or reference to it elsewhere. Several sheets of filter paper were soaked in ammoniacal argentic nitrate and hung up in a closed room of which the paper contained Schweinfurth green. Gas lights were kept burning ten hours, and after they were put out the room was kept closed ten hours longer. The papers, which were blackened, were digested with hydrochloric acid for thirty minutes, and a piece of copper was laid in the solution. A gray deposit was formed on the copper, and the latter, after being washed and dried, was heated in a bulb tube. A white ring was obtained and said to be arsenic, though no further proof was given. Yet, if it were arsenic, which is not decided, it might have had its source in the dust of the room, as well as from a volatile compound.

Halley, in 1858, in a letter to the London Times,[‡] tests the air of a room containing an arsenical wall paper by merely hanging up sheets of paper soaked in ammoniacal argentic nitrate, in which he observes after some time the formation of numerous "well defined crystals of arsenious oxide, visible under a low power microscope." I am inclined to think that this experiment is merely the foregoing, subjected to a newspaper condensation, which has omitted essential details.

Campbell,[§] in 1858, made the following experiment. Strips of arsenical paper, about one square foot in all, were placed in a bottle containing a thermometer and fitted with a double bored cork. Through one boring passed a right-angled hard glass tube, terminating in a spiral, which could be heated by a broad burner. The other boring held an exit tube passing to a solution of potassic hydroxide. Gas jets were kept burning in the room, and air, at a temperature from 16 to 60°, was drawn from the bottle through the solution. Several trials were made, each lasting one hour, and in no case was arsenic detected. How the arsenic was tested for is not stated, but it is not surprising that none was found. The absurdity of the experiment was shown by Taylor * a week or so later.

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[*] Verhandl. d. Verein f. Staatsarzneiwissensch. in Berlin, 1855, I. 47.

[†] *Loc. cit.*, p. 416.

[‡] Pharmac. Journ. and Transactions, 1858, p. 428.

[§] Ibid., p. 520.

Abel,† in the same year, made the following experiments at the instance of the British government. A room was selected having a green unglazed paper containing one fifth of a grain of arsenious oxide per square inch (20 grams per square meter).

1. The room was closed for 36 hours, and then the air was led between four and five hours through a solution of argentic nitrate, and then through a tube containing asbestos soaked in ammoniacal argentic nitrate. No arsenic was found in solution or tube.

2. Five gas flames were burned in the room for several hours, and at the end the air was led through the same reagents with the same negative result. The method used in testing is not given.

3. A glass tube, 3.5 ft. long and 2 in. in diameter, was filled with small pieces of arsenical paper, warmed to 32°, and connected with the reagents as above. The air of the room was led through for a week, and from time to time gas burners were lighted.

4. The air was passed through a strong solution of sulphurous acid and then led for 24 hours through the apparatus.

5. The products of combustion of a gas burner were concentrated by a funnel and led through the apparatus for three days, and again (6) for four days.

7. The paper was roughened by friction and hot air led through for nine days.

8. Strips of arsenical paper with decomposing paste were placed in the same tube, and hot air led over for nine days, with products of gas combustion also. In none of Experiments 3 to 8 was arsenic found in either silver solution or tube. Yet as the method of testing for arsenic is not given, and we do not know its accuracy, the experiments are thus deprived of considerable value.

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* Pharmac. Journ. and Transactions, 1858, p. 553.

† Ibid., p. 556; also British Review, October, 1858, and Schmidt's Jahrbuch, 1859, XLV. 20.

9. 600 grains (39 grams) of emerald-green were distributed in a lot of cotton wool and placed in a jar, into which a tube was plunged containing cotton wool and connected with the silver solution. Air was drawn through at 32° for some time, but no arsenic was detected in the solution.

Phillips,* in 1858, repeated the experiment of Halley. Two closets were used, one containing 48 sq. ft. (4.46 sq. m.) of a paper containing 11.8 grains arsenious oxide, as Schweinfurth green, to the square foot (8.3 grams per square meter), and another containing 53 sq. ft. (4.92 sq. m.) of the same paper. In each closet were placed two dishes, one containing a solution of potassic hydroxide and the other ammoniacal argentic nitrate, besides a sheet of paper saturated with the latter. The closets were closed 72 hours and gas was burned 45 hours in one, the temperature being about 25°. No arsenic was found in the solutions by Marsh's test, but the method of preparing the solutions for the test is not given. The paper also contained no arsenic, but was of course dark, and contained crystals of argentic nitrate. Phillips considered that his test proved the absence of the vapor of arsenious oxide, but he has apparently proved the absence of any arsenical dust. The use of the Marsh test is sufficient to account for this, as the amount of dust that might fall in 72 hours from such a paper would quite possibly show no arsenic by the simple Marsh test. As a test for the presence of a gaseous compound like arseniuretted hydrogen, such an experiment is of no value.

Paul,† in the same year, thinks that Campbell's and Abel's work disproves the idea that arsenic is volatilized, and concludes from the negative results that the arsenic cannot leave the paper at all, paying no attention to the possibility of the detachment of arsenical dust.

Oppenheimer,‡ in 1859, was the first to show the presence of arsenic in the dust of a room.

Schmidt and Bretschneider,§ in 1859, placed a mixture of Schweinfurth green, meal, and water in a large flask closed by a double bored cork, through one boring of which a tube led to an argentic nitrate solution protected from the light, the other hole being presumably fitted with a tube reaching under the mixture. In three similar flasks the same mixture was placed, and to them were added, respectively, putrid cheese, putrid blood, and yeast, and each flask was connected with an argentic nitrate solution as before. All four flasks were kept at 32° for six weeks, and air from them was passed through the silver solutions. A slight black precipitate was formed in each, but the liquid on being tested in the Marsh apparatus showed no arsenic. No odor was observed, and Schmidt and Bretschneider considered the fermentation to have been stopped. They decide that poisoning cannot take place in damp rooms from a volatile arsenical compound, and that it is more likely that the trouble comes from the detachment of dust in dry rooms. These experiments are more in line with recent work than those preceding, and they are the first that are worthy of much consideration. Certain conditions, not then understood, might have operated against the formation or detection of a gaseous compound. Although the Berzelius-Marsh test may have been used, we do not know the limit in Schmidt and Bretschneider's hands, and the treatment of the silver solution is not given.

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* Jour. Franklin Inst., [3], XXXVI. 397; also Lond. Civ. Eng. and Arch. Journ., 1858.

† Pharmac. Jour. and Transactions, 1858, p. 616.

‡ Ref. by Eulenberg, *loc. cit.*, to Heidelberger Jahrb. d. Lit., 1859, p. 810.

§ Untersuch. z. Naturlehre d. Mensch. u. Thier. v. Moleschott, VI. 146.

Wittstein,* in 1860, advances the idea that the arsenites in the coloring matter are changed to arseniates at the cost of part of their oxygen ($5\ As_2O_3 = 3\ As_2O_5 + As_4$), and that metallic arsenic is volatilized.

Sonnenschein,† in 1869, made the following experiment in a damp room on the ground floor in which the paper was very arsenical, the occupant of which was affected by symptoms attributable to arsenical poisoning. The air of the room after passing through a wash-bottle was led through a hard glass tube heated to redness. After many hours' heating there appeared a perceptible mirror, which Sonnenschein concluded to be arsenic, but he was unable to determine the nature of the volatile compound. The deposit, however, received no confirmatory test.

Fleck,‡ in 1872, conducted the following series of experiments.

1. A five-litre tubulated bell jar resting on a ground-glass plate was covered on the inside with paper smeared with Schweinfurth green (about 15 mgr. arsenious oxide per sq. cm.). The paper was fastened by a paste of potato starch. Through the tubulus passed a cork carrying one right-angled tube reaching to the bottom of the bell jar, and another to just below the cork. The jar was closed and allowed to stand.

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* Quoted by Eulenberg, *loc. cit.*, p. 414; also Schmidt's Jahrb., CX. 88.

† Handbuch d. gericht. Chemie, 1869, p. 153.

‡ Zeitschr. f. Biologie, VIII. 444; also, Dingl. Polyt. Jour., CCVII. 146.

2. A glass flask fitted with tubes like the bell jar was covered on the inside with a paste of gelatine and Schweinfurth green, closed, and allowed to stand.

3. In a bell jar, fitted as in Exp. 1, was placed a dish containing a paste of Schweinfurth green and water.

4. In a similar bell jar was placed a dish containing arsenious oxide and water.

Experiments 1 and 2 should decide whether an arsenical gas could be given off by decomposition of an arsenic compound with organic matter and moisture, while Experiments 3 and 4 would show if any came from an arsenic compound and water alone. In Experiment 1 there was soon a formation of mould and odor of mould, and in Experiment 2 an odor of decaying gelatine. No garlic smell was noticed in either. The temperature was 17 to 18°.

Jar No. 1 and flask No. 2 having been closed for three weeks, at the end of that time the air from the former was led for 24 hours through an absorption bottle containing 150 c. c. water, the air in the jar being renewed about a hundred times. The water was then introduced into a flask containing zinc and acid, from which hydrogen had been passing into argentic nitrate for one hour without result. The silver solution was discolored in 15 minutes, and after an hour was completely black. The filtrate became cloudy on addition of ammonia, but was not tested further for arsenic, the black precipitate being considered sufficient indication of the formation of arseniuretted hydrogen. The same result was obtained from Experiment 2.

Jars 3 and 4 were closed for eight days and the air from them drawn through water as before. The solution from No. 3 gave a very weak action on the argentic nitrate, while that from No. 4 gave none at all.

The first jar and the flask were again closed for some time and the air led through 150 c.c. of argentic nitrate (1–100). The air, before entering the two vessels, passed through a tube of calcic chloride, and between the jar and the argentic nitrate was placed an empty tube to catch dust or anything that might be condensed. No dust or moisture was noticed in this tube. A slight gray deposit was formed in the silver solution and the filtrate gave a turbidity with ammonia.

From the fact that the color of the paper was not lessened, Fleck concludes that the Schweinfurth green was not decomposed, but that the formation of arseniuretted hydrogen was due to decomposition of arsenious oxide. From the amount of silver precipitated he reckons the amount of hydride formed at 0.01 c. c. in the five litres.

Fleck also mixed five grams arsenious oxide with two grams starch to a paste in a 500 c.c. flask, and noticed formation of mould and crystals of metallic arsenic! Testing this as before, he found arsenic.

No *proof* of the formation of an arsenical gas is given by these experiments. The fermentation, which was greater in the first series of experiments, undoubtedly produced enough volatile organic matter to reduce the silver solution in the light. The failure to test the silver solutions for arsenic deprives the results of value, though it is quite possible, in the light of recent work, that a volatile compound was formed.

Hamberg,* in 1874, tested the air of a room for the presence of a volatile arsenic compound. He used a large dry room which had been papered for 25 to 30 years with a paper of which 1 sq. cm. gave, in the Berzelius-Marsh tube, a thick opaque crust of arsenic 6 cm. long. Arsenic and arsenious acids were found in the coloring matter. The persons who let the room had not perceived any injury to themselves or to others.

A series of tubes was hung on the wall opposite the windows, and the air of the room was drawn through them for a month, the door and windows being closed. During the experiment an alliaceous odor was occasionally observed. The first four tubes were U tubes, of which the first was empty and the next three contained cotton wool. Next came two Liebig bulb tubes with a solution of argentic nitrate in each, and between these and the aspirator was an empty guard U tube. 2,160 litres of air were drawn through the system. After a week a black precipitate appeared in the first silver solution, and later in the second.

The tests were made by the Berzelius-Marsh method. From the first U tube a slight film of arsenic was obtained, in the second (containing cotton) likewise a trace, while the third and fourth contained none. The silver solution was filtered and the precipitate found to be silver, with some sulphide of silver. Ammonia gave a faint yellow precipitate in the filtrate. The latter was precipitated with hydrochloric acid, and the filtrate after evaporation with sulphuric acid introduced into the Marsh flask. In ten minutes a brown film appeared, which increased after an hour to an opaque brown crust. The second silver solution, treated similarly, gave but a faint film.

Hamberg is the first from whose results a definite conclusion can be drawn, and his work is of particular value from having been done on the air of a room. The methods of the experiment are only open to criticism in that the freedom of reagents and apparatus from arsenic is not stated.

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* Pharmac. Journ. and Transactions, [3], V. 81; also, Nord. Med. Archiv, VI. No. 3.

Selmi,* in 1875, investigated the question of the formation of hydrogen by the action of mould. After showing that sulphuretted hydrogen was developed in decaying organic matter over which sulphur had been sprinkled, he reasoned that arseniuretted hydrogen would be formed by the action of moulds on arsenical organic matter. He accordingly sprinkled very finely powdered metallic arsenic over a mixture of horse dung and flour, on which mould was growing vigorously, and placed the preparation in a tubulated bell jar. Strips of paper moistened with argentic nitrate were hung from the top of the jar. The tubulus at the top was closed by a stopper with two holes, carrying tubes for ingress and egress of the air that was drawn through by an aspirator. After five days during which time the bell jar was in the dark, the paper was found to be slightly reddened. It was then treated in a dish with potassic hydroxide, which set free, besides ammonia, a peculiar disagreeable odor. The alkaline residue was then neutralized with nitric acid, evaporated with sulphuric acid to destroy organic matter, and introduced into the Marsh apparatus. After an hour a distinct metallic ring was obtained which, after solution in nitric acid and evaporation, gave a red color with argentic nitrate.

A second trial under the same conditions resulted similarly. In a third and fourth, mouldy lemons were spread with arsenic dust and covered by a funnel from the top of which hung strips of argentic nitrate paper. After 38 hours the organic matter of the paper was destroyed by nitric and sulphuric acids, and the residue, introduced into the Marsh apparatus, gave a well defined ring. Five other trials were made under varying conditions, and in every case a ring of arsenic was obtained. In a tenth experiment arsenious oxide was sprinkled on mouldy starch paste, and placed under a bell jar through which air was drawn. Strips of argentic nitrate paper hung in the bell jar acquired in eight days a red tint, and yielded in the Marsh apparatus a ring of arsenic.

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* Ber. d. deutsch. chem. Gesells., VII. 1642 (Corresp.); Schmidt's Jahrbuch, 1875, CLXVIII. 60; Just, Botan. Jahresber., 1876, p. 116. All of these refer to a paper of Selmi's published in the Accademia delle Scienze of Bologna, entitled "Nuovo Processo Generale per la Ricerca delle Sostanze Venefiche," in which, however, the above work does not appear. I have recently obtained a reprint of this article (Bologna, 1875) with which is incorporated "Osservazioni sullo Sviluppo d' Idrogeno Nascente dalle Muffe," and the extract given above is from the latter paper. The abstracters have evidently referred to this separate monograph, and all fail to note the bearing of it upon the question of the formation of a volatile arsenical compound.

Selmi considered that the results pointed to the formation of an arsine, and that the formation of hydrogen by moulds was confirmed conclusively.

In the light of recent work there may have been a volatile arsenical compound formed in Selmi's experiments. Yet we cannot accept them as conclusive because of the neglect to provide against the possible reduction of the silver paper by the dust particles in the bell jar. Had the filtered air given the above results, they would have been of more value. Besides this the freedom of the reagents from arsenic is not shown. No mention is made of any alliaceous odor from the decomposing matter. The odor from the silver paper after adding alkali may be analogous to that noticed later by Hamberg, Gosio, and myself, but it is not sufficiently characterized by Selmi to draw any definite conclusion in regard to it.

The results of Fleck and Hamberg were accepted by many as conclusive, and more recently the evidence of Selmi has been considered corroborative. It was some time before Selmi's results became generally known. His paper did not obtain wide circulation, and the abstracts quoted above treated his work as bearing only on the general question of the development of hydrogen by moulds, and not on the formation of a volatile arsenical compound.

Professor Chandler of Columbia, in the course of his testimony before a committee of the Massachusetts Legislature in March, 1886, stated that two of his students, Messrs. Morewood and Drummond had. in 1879, under his directions, passed the air from a vessel containing Paris green and paste into an argentic nitrate solution for a number of days, and failed to find any arsenic. The mixture was then allowed to decompose in a warm place and the air was tested for arsenic with the same result. They then covered a square yard of paper with Paris green and paste, placed it in a vessel, and drew air over it into argentic nitrate for many days. The result of this was also negative. As no further details were given, and the work has not, to my knowledge, been published, no conclusion can be drawn as to the possibility of finding small amounts of arsenic by the method used, whatever that might have been.

Bartlett,* in 1880, tried the following experiments. He first passed a stream of hydrogen from sodium amalgam over a quantity of wall paper, free from arsenic and antimony, contained in a large glass vessel, and directed the stream against paper moistened with argentic nitrate and screened from light. There was no action after 12 hours, nor did the addition of ammonia to the hydrogen cause any blackening. He then passed ammoniacal hydrogen from sodium amalgam over moist paper containing a large quantity of arsenic, and obtained what he calls "characteristic reactions" for arsenic, probably a reduction of the silver paper. Of course the blackening of paper cannot be taken as proof of the presence of arseniuretted hydrogen, nor is the formation under these conditions to be expected. Bartlett notes that he intends to pass ammoniacal hydrogen over 20 sq. yd. of paper for a long time in the hope of collecting the resulting argentic arsenite, but he has not, to my knowledge, published anything further on this subject.

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* The Analyst, 1880, p. 81.

Forster,* in 1880, tried the following experiments to ascertain whether arsenious oxide was volatilized from Scheele's green, and whether arseniuretted hydrogen could be given off from a paint containing this pigment. Air was drawn through a bottle filled with glass covered with Scheele's green, and, after filtration by cotton wool, was passed into a solution of potassic hydroxide. One experiment lasted one day, two lasted two days each, and a fourth seven days, the temperature of the bottle being from 45 to 50°. In each case the potassic hydroxide was neutralized by sulphuric acid, and by the Marsh method gave no arsenic. In a second series the bottle was filled with shavings smeared with a paint of linseed oil, turpentine, and Scheele's green. The air was not filtered and passed through two U tubes containing potassic hydroxide and argentic nitrate respectively. Two trials were made for five days and two for six days, at a temperature of 14°; a fifth lasted nine days. The potassic hydroxide solution, treated as before, gave no arsenic. The silver solution was precipitated by hydrochloric acid, and sulphuretted hydrogen led through the filtrate for twelve hours. Not getting a precipitate, Forster concludes the absence of arsenic, but tests further by the Marsh method with a negative result.

Giglioli,† in 1880, after a series of experiments lasting eight months, declared himself opposed to the theory of Selmi, and favored the assumption that chronic arsenical poisoning was due to dust alone. He used moist bread and saccharine liquids, to which arsenious oxide had been added. The preparations were exposed to the air, and, after the mould had formed, were placed in a vessel through which a current of air was passed into an absorbent. Argentic nitrate and auric chloride were used, and in some experiments the air was led through a hot Berzelius-Marsh tube. No arsenic could be detected in the air above the mould, nor was there any odor.

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* Proceedings Med. Soc. of London, V. 41; Chemical News, 1880.

† Ann. d. R. Scuola sup. d'Agricoltura di Portici, II. 165; Gazz. chim. Ital., 1881, p. 249.

Bischoff,* in 1882, during the examination of some fodder with which arsenic had been mixed with intention of poisoning, placed a part of it, while still moist, in a covered glass dish. After some weeks he observed that mould had collected in the mass, and, on opening the dish, noticed an odor which, from its garlic nature, he concluded to be due to arseniuretted hydrogen. Strips of paper moistened with argentic nitrate were at once turned brown. This was considered by Bischoff to confirm the theory of the formation of arseniuretted hydrogen during fermentation. It is greatly to be regretted that this experiment, which has actually furnished a clue to the recent successful investigations, should not have been carried out properly. There was undoubtedly a volatile arsenic compound present, yet one cannot, in such an important question as this, accept an odor or a blackening of silver paper as indicative of arsenic.

Hamberg,† in 1886, published the result of an investigation, extending over nearly nine years and a half, on the change produced in arsenious oxide in contact with decaying animal matter. I give the experiment in some detail, because an incorrect and misleading idea of it seems to have been obtained from the abstract quoted.

In a twelve-litre flask were placed portions of a body; lungs, liver, kidneys, and intestines, mixed with broken glass and sand. The mixture was moistened with a solution (it is not stated whether it was acid or alkaline) of one gram of arsenious oxide, covered with sand and aluminous earth, and the whole saturated with water. The flask was connected with (1) a tube containing cotton wool, (2) a tube containing test paper, (3) an absorption tube with a 4% solution of argentic nitrate, (4) a U tube to catch any of the silver solution which might be mechanically carried over, and to the last was attached a Finkener aspirator. Air was drawn from outside the laboratory through the flask and system of tubes at the rate of 15–23 litres daily. Mould was noticed in 16 days. From June 4, 1876, to November 21, 1885, the air of the flask was tested at irregular intervals, as detailed below, and the presence of arsenic in the silver solutions determined. In every solution except the first, reduction of the silver was noticed, and very often a yellowish sediment was formed. The odor of the air in the flask was very disagreeable, and in one case brought to mind the odor of either arseniuretted hydrogen or kakodyl. Sometimes the silver solution had a strong odor. Argentic nitrate paper, hung in the flask, turned dark very quickly, but plumbic acetate paper was not affected. Auric chloride paper was introduced in the last year, but was not reduced. Ammonia was given off freely, especially towards the last.

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* Vierteljahr f. gericht. Med., N. F., XXXVII. 163.

† Pharm. Zeitschr. f. Russland, XXV. 779; Behang t. k. svensk. vetenskabs-akad. Handl., Bd. 12, II., No. 3; Fres. Zeitschr. f. analyt. Chem., XXVI. 788, Ref.

November 21, 1885, as the last silver solution tested gave but a faint deposit in the reduction tube, and an argentic nitrate paper hung in the flask was not blackened, it was concluded that the action had ceased. The residue in the flask was then examined for arsenic. An aqueous extract yielded 149 mgr. arsenious sulphide and the residue from this, extracted with very dilute acetic acid gave 67 mgr. The remainder of the mass, consisting of organic matter, earth, sand, etc., was treated with hydrochloric acid and potassic chlorate, and from the filtered solution 469 mgr. arsenious sulphide were obtained, making 685 mgr. in all, corresponding to 551 mgr. arsenious oxide. The residue from the treatment with hydrochloric acid and potassic chlorate was not examined further, and it is quite possible that the extraction was not complete.

The arsenic was found in the first two extracts as arseniate, but a similar condition could not from the method of extraction be shown in the residue. Undoubtedly the lower oxide was to a great extent changed to the higher. Hamberg concluded that the remaining 449 mgr. had passed away as some gaseous compound, though it is not to my mind certain that these figures are not too large by the amount which may have remained in the last residue.

A consideration of the amount actually absorbed is interesting, and throws some light on the nature of the volatile compound. In the interval between two successive examinations of silver solutions, or when the flask was opened to test odor or action on test paper, much of the gas may have escaped, yet it can be fairly assumed that most of it came in contact with the absorbents. In the first examination (after a run of five months) there were found 1.1 mgr. of arsenious sulphide, corresponding to 0.88 mgr. of the oxide. In the second test (additional run of three months) the presence of arsenic in sediment and solution was confirmed qualitatively by different reagents, and I assume that the precipitate of arsenious sulphide was not weighable. In the third test (ten months additional run) the sediment gave 0.8 mgr. of sulphide (0.64 mgr. oxide) while the solution gave a "weak reaction." Here again the precipitate seems to have been too small to weigh. In the succeeding determinations the attempt to estimate gravimetrically was abandoned, and the Berzelius-Marsh method was used. Eighteen months had elapsed during which time the action had apparently been at its height, as after sixteen months more the sediment in the fourth test gave no arsenic and the solution an amount much less than the preceding. The rest of the tests gave diminishing amounts from the solutions, while none of the sediments, except the last. contained any arsenic. The silver solutions were precipitated with hydrochloric acid, filtered, and the filtrate, after evaporation with sulphuric acid, was added to the Marsh apparatus.

Unfortunately, the quantitative estimation of arsenic by the Berzelius-Marsh method was unknown to Hamberg, but I have placed the most accurate estimate possible on the mirrors from his description of them, and tabulate the results of the absorption tests on the opposite page.

In the interval between the third and fourth tests, the argentic nitrate solution was one day replaced by a tube containing fused calcic chloride, and the air led through a glowing tube for eight hours. No deposit of arsenic was found. From January (15?), 1882, to March 28, 1882, a second argentic nitrate solution was placed after the first, and, on examination at the same time, contained no arsenic. After this, although a second solution was used, there is no record of its having been tested beyond the statement that the sediment formed was very slight. From July 14, 1885, to October 28, 1885, the argentic nitrate was replaced by a tube containing nitric acid (strength not given), and for most of the time there was an argentic nitrate solution after it. This acid yielded over a gram of ammonic nitrate which was not arsenical. The argentic nitrate solution was kept in a month longer and gave only a faint deposit. This was the last test.

Making allowance for the second test there were found from 2 to 3 mgr. of arsenic as arsenious oxide in the air passed into the argentic nitrate, if we assume that each deposition of an arsenical mirror was carried to completion. This is, however, only from 0.44 to 0.66% of the 449 mgr. which are supposed to have escaped as a gaseous com-

No.	Date of Examination.	Duration of run in Months.	Character of Mirror.	Estimate of Mirror by Standard in Mgr. As_2O_3.*
1	1876, Nov. 10.	5	Estimated from As_2S_3.	0.88
2	1877, Feb. 12.	3	Qualitative determination.	—
3	1877, Dec. 21.	10	Estimated from As_2S_3.	0.64
4	1879, Apr. [15?]	16	2 cm. long in 20 min.; "nearly opaque."	0.08
5	1880, May 11.	13	2 cm. long in 35 min.; "slightly transparent."	0.05
6	1880, Sept. [5?]	4	2 cm. long; "partly opaque."	0.05
7	1881, Apr. 13.	7	2 cm. long in ten min.; "nearly opaque."	0.06
8	1882, Mar. 28.	11	"Distinct."	0.03
9	1882, May 11.	2	"Weak deposit."	0.02
10	1883, Feb. 9.	9	"Only weak."	0.02
11	1883, Sept. [15?]	7	"Only weak."	0.02
12	1885, July 14.	22	"Only weak, transparent."	0.02
13	1885, Oct. 28.	3	From nitric acid; no mirror.	0.00
14	1885, Nov. 21.	1	From solution; "faint, scarcely perceptible."	0.01
			From sediment; ditto.	0.01
			Total	1.89

pound, and from 0.2 to 0.3% of the total amount in the flask. Hamberg states that by addition of all the amounts separated from the silver solutions, partly as sulphide, partly as metallic arsenic, he finds that the greater part of the arsenical gas was not absorbed, and he thinks that possibly the silver solution was only partially able to decompose the gas. Whatever estimate he may have made from the mirrors is not stated; hence we cannot know what amount he thinks was recovered. As my own experiments have shown the inadequacy of 2% argentic nitrate for absorption of the volatile compound and the chance for loss in preparing the solution in the above manner for analysis, the cause of loss is quite clear. The quantitative estimation of the amount of volatile compound formed in this experiment is subject to too many chances for error to make it of any value except as a means of throwing light on subsequent work. The main fact of the formation of a volatile compound is proved, though the mode of formation is not shown, and its applicability is not extended to the particular question at issue.

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* According to the method described by me in these Proceedings, XXVI. 24.

Here again has Hamberg given us results which are trustworthy, and his two experiments are the only ones thus far in this historical sketch against which valid objection may not be raised, though in regard to the second I can only repeat what I have said of the first as to absence of detail in the method.

Hamberg, assuming the volatilization to be proved, concludes that in the corpses of persons poisoned by arsenic a similar change takes place, that in the course of years arsenic is given off as a gaseous compound, and that this explains the disappearance of arsenic which has been observed or conjectured by many toxicologists in the examination of parts of exhumed bodies.

Stokes,* in 1888, during an examination of wall papers, fabrics, and domestic articles for arsenic, placed about 300 sq. inches (about 0.19 sq. m.) of arsenical muslin in a glass tube connected with a smaller heated tube. Air was drawn through for six hours, and passed from the hot tube into an argentic nitrate solution. No arsenic was detected in the hot tube or in the solution. The large tube was then heated to 38° and air passed through the system for six hours more, but with the same result. This experiment would only determine whether the arsenical color was itself volatilized, but the duration is so short and the test for arsenic so indefinite that the experiment is of little or no value.

My friend Professor Kinnicutt, of Worcester, Mass., has very kindly allowed me to include here some experiments which he conducted about six years ago but has never published.

1. A room 18 by 20 feet was selected, with a wall paper containing 0.1 grain of arsenic per sq. yd. (7.8 mgr. per sq. m.). The windows and door were closed, and the air of the room was drawn at the rate of about 120 bubbles per minute through a chloride of calcium tube filled with cotton wool and then through 5% argentic nitrate solution. After seven days neither the cotton nor the silver solution contained any arsenic. The latter had a slight black deposit. The method of analysis was essentially the same as in my first series of experiments.

2. A number of pieces of cardboard were covered, by means of

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* Chem. News, LVIII. 190.

starch paste, with wall paper containing arsenite of copper, so that in the surface exposed there were about 400 mgr. of arsenious oxide. These cardboards were then placed in a specially constructed tight box with glass windows, arranged so that air could be drawn from end to end. The air entering the box passed through a dilute solution of sodic hydroxide. On leaving it passed through a chloride of calcium tube filled with cotton wool, next through a Liebig bulb tube with 5% argentic nitrate protected from the light, and finally through bulbs filled with nitric acid (sp. gr. 1.12). Air was drawn through the system for two and a half months, averaging seven hours per day. At the end of this time a large amount of mould had formed on the paper. The cotton wool gave a marked test for arsenic, but the silver solution did not show the slightest trace. The nitric acid evaporated with sulphuric acid was also free from arsenic.

3. The box used in No. 2 remained over four years in the cellar of the laboratory, and had become filled with mould, the windows being covered with moisture. A similar series of absorbents was connected, and air was drawn through the system for a week, night and day. The cotton wool, silver solution, and nitric acid were tested as in No. 2, but in no case was any arsenic found.

The evidence presented above, with the exception of the experiments of Fleck and the earlier work of Hamberg, was collected after my first series of experiments was completed. These, which were intended to repeat the work of Fleck and Hamberg, and which were based on the assumption that the volatile compound, if formed, would be arseniuretted hydrogen, are given below. On account of the negative results they are not presented in as much detail as originally intended, for the conclusion derived from them at that time was shown to be erroneous by the results of the second series.

FIRST SERIES OF EXPERIMENTS.

Fermentation in Solution. — *Experiment* 1. — 20 grams potassic arsenite dissolved in water were mixed with syrup, flour, and part of a yeast cake, and placed in a large flask fitted with a double bored cork. Through one hole reaching to the bottom of the flask, passed a right-angled tube connected with the tubulus of a side-neck test-tube (A) the latter being half filled with a 2% solution of argentic nitrate and fitted with a cork through which passed a right-angled tube to the bottom of the test-tube. In the second hole of the stopper of the flask was placed an empty Kempff washing bottle (B), reaching just below the stopper and serving as a safeguard against back pressure as well as to catch any of the arsenical mixture that might be mechanically carried up. Through the rubber stopper of the first washing bottle was passed a second (C), containing about 50 c.c. of the same argentic nitrate solution to absorb the volatile compound. This bottle was connected with the right-angled tube of a side-neck test-tube (D), similar in arrangement to A, and serving as a guard against contamination of the silver solution in C from this end. To the tubulus of D was attached the water-pump. The flask was kept at 30° for 36 days and the fermentation was marked, air being drawn through nearly all the time. At the end there was no perceptible change in the solution in the bottle C. This solution was tested as follows. A clean new evaporating dish was heated with about 3 c. c. strong sulphuric acid, and the acid after cooling was diluted with about eight parts of water and introduced into the Marsh reduction flask.* No mirror appeared in 45 minutes, at the end of which time was added the solution obtained from the argentic nitrate. This had been heated to boiling, and precipitated with hydrochloric acid, the filtrate being evaporated with the addition of a few drops of nitric and sulphuric acids until it fumed strongly. Water was then added, and the cold solution put into the reduction flask. No mirror appeared although the action continued for 45 minutes, thus showing no absorption by the silver solution of any volatile compound of arsenic from the fermenting mixture.

Experiment 2. — In the following two experiments the dilution was made very great, in case this condition should affect the formation of the volatile compound. The arrangement of the flask and rear guard tube (A) was as in Exp. 1. Next to the flask was placed a short straight tube filled with fused calcic chloride (B), and to this was connected a washing bottle (C) with 2% argentic nitrate. Diluted syrup solution and yeast were placed in the flask, and to it were added 10 c. c. of a standard solution of arsenious oxide equivalent to 10 mgr. As_2O_3. The apparatus closed at A was left for nine days at the ordinary temperature. Fermentation set in at once and continued until the end. The silver solution was somewhat darkened, probably by the action of light and some volatile organic compound. Air was drawn through the system until the air in the flask had been several times replaced. The silver solution, treated as before, gave no arsenic.

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* The method used in all the experiments was the modification of the Berzelius-Marsh described by me in these Proceedings, XXVI. 24.

Experiment 3. — The arrangement of flask and tubes, contents of flask, etc., were as in Exp. 2, except that a tube containing cotton wool was used instead of calcic chloride. The action went on for 16 days, and at the end of that time there was a slight grayish black precipitate in the silver solution. The latter, however, yielded no arsenic.

Fermentation on Paper. — *Experiment* 4. — A large bell jar, having a tubulus at the top and standing on a well greased ground-glass plate, was fitted with a system of tubes and absorbents similar to those of Exps. 1–3. In the jar were placed several pieces of a wall paper containing 110 mgr. As_2O_3 per sq. m., giving a total amount of 67 mgr. over a surface of about 0.6 sq. m. The back of the paper was smeared with a paste of flour and syrup, to which part of a yeast cake had been added. Air was drawn through the system for fifteen days. There was apparently considerable reduction of the silver solution and a quantity of black precipitate. This was filtered off, and the filtrate treated as previously described. After a 45 minutes' test of the apparatus, the solution gave, after an hour's run, a scarcely perceptible deposit, which did not look like arsenic, and could not be proved to be arsenic.

Experiment 5. — The apparatus was the same as in Exp. 4. Another wall paper was taken, having a surface of about 0.89 sq. m. and containing in itself about 45 mgr. As_2O_3. To the flour paste smeared on the back were added about 7 grams arsenious oxide. Air was passed through for 19 days, and at the end of that time the reduction of the silver solution was more marked than in Exp. 4. The filtered solution was treated as before, and gave, after 30 minutes, a very slight deposit, not resembling arsenic, and giving no confirmatory test.

Experiment 6. — This was a continuation of Exp. 5 with the same apparatus and prepared paper, but instead of the silver solution a small quantity of strong sulphuric acid was used as perhaps a better means of absorbing the volatile arsenical compound. Air was drawn through for 15 days. The acid was darkened and sulphur dioxide had been formed. The acid was evaporated with a little nitric acid, diluted, and added to the reduction flask, but no mirror of arsenic appeared in 30 minutes.

Experiment 7. — This was a continuation of Exp. 5 in exactly the same manner, the sulphuric acid of Exp. 6 being replaced by a silver solution. Air was passed for eight days, and the reduction was somewhat less than before. The test of the solution was entirely negative.

Experiment 8. — In order to try the effect of alkaline fermentation about 0.5 sq. m. of brown wrapping paper was smeared with flour paste containing 8.5 grams arsenious oxide and a quantity of lime, and placed in the same bell jar without removing the preparation used in Exps. 5–7. The total amount of arsenious oxide was therefore about 15.5 grams. Air was passed for 17 days. There was much mould in the bell jar, and the silver solution was slightly reduced. No arsenic, however, was found in it.

Experiment 9. — In this and in the following experiment the main deviation from the previous trials was in the amount and character of the arsenic compound, and the duration of fermentation. In a large bell jar, fitted with a similar system of absorbents to that of Exp. 1, was placed about 1 sq. m. of a wall paper containing only a small amount of arsenic, and on this was smeared a paste of flour and syrup, to which had been added 10 grams arsenious oxide and part of a yeast cake. After action for 36 days, during which time air was drawn through slowly, the silver solution was examined but gave no arsenic. Very slight reduction had taken place, the light not being as strong as in the previous experiments.

Experiment 10. — The conditions of this experiment were exactly the same as in the preceding, with the substitution of 10 grams of Paris green for the arsenious oxide. The result was also the same.

Direct Experiments on the Air of Rooms. — Experiment 11. — The room in which this experiment was performed was a large attic chamber. The surface of paper exposed was about 60–70 sq. m., each containing 280 mgr. arsenious oxide. The frieze and ceiling contained traces only, 0.8 mgr. and 1.0 mgr. respectively, so that the total amount of arsenic may be estimated at about 18 grams. The occupant of the room spent much of his time in it, and showed symptoms attributable to chronic arsenical poisoning. The room was at about 25°.

In order to absorb the volatile compound, if present, a washing bottle similar to those used in the previous experiments was partly filled with a 2% solution of argentic nitrate and connected with an aspirator. In order to free the air from arsenical dust, it passed, before reaching the silver solution, through two tubes filled with cotton wool. In four days, the room being closed, about 750 litres of air were drawn through the bottle. There were then a few black specks in the solution. This, after filtration, was analyzed as before, the apparatus having been shown to be free from arsenic, and gave no mirror in 40 minutes.

Experiment 12. — The paper in this room had a surface of about 32 sq. m., each containing 30 mgr. arsenious oxide, making a total of about one gram, a rather small amount for the experiment and the size of the room, but the paper was not quantitatively analyzed until afterward. The room was warm, and was kept closed during the trial. No complaint had ever been made by the occupant of symptoms of arsenical poisoning. The apparatus was set up as in Exp. 11, and air was drawn through it rapidly for five days. No reduction of the silver solution was visible. The latter, after treatment in the usual manner, gave no indication of arsenic.

Experiment 13. — This room was considerably smaller than the other two. The total amount of arsenic in it was about 3.6 grams. No symptoms of arsenical poisoning were ever noticed by the occupant, a boy in vigorous health, who occupied the room only at night. The room was closed and kept at 25°. The apparatus was set up as in the previous experiments and 6,720 litres of air were drawn through the system. There was no perceptible darkening of the silver solution, and, on analysis by the same method as in the previous trials, it was found to be free from arsenic.

Experiment 14. — The conditions under which this experiment was performed were, as regards warmth and dampness, more favorable to the formation of a volatile arsenical compound than those of the three previous trials. The occupant of the room suffered from symptoms which were clearly due to arsenic.* The total amount of arsenic present in paper and curtains was about 3.9 grams. During the experiment the room was closed, and the air was at about 30° and damp. The apparatus was similar to that used before, except that between the guard tubes of cotton wool and the silver solution was placed a small quantity of strong sulphuric acid, just as in Exp. 6, as an additional means of absorption. Air was drawn through the system, at intervals for 22 days, the total amount being 1,323 litres. The acid had increased in volume considerably by absorption of moisture, but there was no evidence of reduction as in Exp. 6. The silver solution was slightly darkened and contained a slight black precipitate. Neither sulphuric acid nor silver solution gave any test for arsenic.

In none of the above trials was any alliaceous odor observed, either from the fermenting material or in the air of the rooms.

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* This case (2) is described in the following article.

The result of these fourteen experiments was entirely negative, though they were carried on under widely varying conditions, and by a method better adapted to detect small quantities of arsenic than any before used. On referring to the previous work cited above, the evidence seemed to be greatly in favor of the conclusion reached by my own results, the work of Hamberg being the only positive evidence in favor of the formation of a volatile arsenical compound. Yet there were two points that still gave hope of the correctness of the volatile compound theory : first, the clinical evidence of undoubted poisoning where there was no chance for absorption of dust; and secondly, the fact that in none of the experiments had any quantity of air been tested which approached the amount daily inhaled by an average man.* The amounts used would have perhaps sufficed if the volatile compound were arseniuretted hydrogen, but, supposing it to have been a compound not completely absorbed by argentic nitrate, (as it turns out to be,) a very small amount might have escaped absorption, which as arseniuretted hydrogen would have been easily found.

Though I did not consider the question fully settled, I thought the evidence against the volatile compound theory sufficiently good to warrant the publication of the results thus far obtained. This I was preparing for when notice of the preliminary paper † of Gosio reached me. I wrote to Dr. Gosio at Rome, who after the completion of his work sent me, in September, 1892, copies of the two monographs cited below, and at the same time, with the greatest kindness and consideration, placed at my disposal an admirably prepared set of tube cultures of *Penicillium brevicaule.*

THE WORK OF GOSIO.

Gosio's classic monograph ‡ has received little attention from the abstracters, and I therefore present his results here in considerable detail. I judge that much of the work mentioned in my historical sketch has escaped his notice, since he cites Selmi as the most reliable authority for the volatile compound theory, and refers to the very insufficient results of Forster as the basis for support of the dust theory. He does not mention Hamberg's first paper, and has apparently seen only the wretched abstract of the second quoted above, for he is unaware of some important points in that paper which were similar to his own experience. He quotes the work of Fleck and of Giglioli, and that of Johannson * and Binz † on the tolerance of arsenic by saprophytes. But the most important result he considers to have been obtained by Bischoff, though his judgment is influenced undoubtedly by the fact that his own results have shown the odor to be a positive indication of the presence of the volatile compound, whereas, in Bischoff's experiment it was only an assumption, and not backed by experimental proof. Other investigators than the above are not mentioned.

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* Estimated to be about 12,000 litres in 24 hours, from the statement of Foster, Textbook of Physiology, 5th ed., p. 551, that the amount of tidal air is 500 c.c., and that the number of respirations is 17 per minute.

† Science, XIX. 104, abstract from a preliminary communication to the Congress of Hygiene held in London in 1891.

‡ "Azione di Alcune Muffe sui Composti fissi d' Arsenico," Ministero dell' Interno, Laboratori Scientifici della Direzione di Sanità, Roma, 1892.

Gosio at the inception of his work considered that a volatile compound could be formed by the action of mould on arsenical organic matter, though positive proof was wanting, and the mechanism of the reaction was entirely inexplicable. He set himself the following plan of work: —

1. To show whether from arsenical culture ground, exposed to spontaneous inoculation from various surroundings, there could be developed a volatile arsenical compound.
2. If so, to isolate the germs which could effect this transformation and to characterize them.
3. To discover in what arsenical compounds the activity of the organisms manifests itself most markedly; whether this is to be extended to products used in the arts; and to find out what conditions favor and what retard the action.
4. To study the volatile compound.
5. To describe the mechanism by which this gas is produced through the biological energy of micro-organisms.

The first question was answered by an experiment similar to Bischoff's. Potato pulp containing from 0.5 to 1% of arsenious oxide was exposed to the air of a cellar. Abundance of mould appeared in a short time, and at the end of a week an intense alliaceous odor was developed. The pulp was then placed in a glass vessel, through which air was drawn for two weeks into a hot solution of argentic nitrate, the air being filtered by cotton wool. The usual blackening took place, on which Gosio very properly lays little stress, and the solution, freed from silver by hydrochloric acid and filtration, gave "characteristic reactions for arsenic."

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* Archiv f. exper. Pathol., II. 503.

† Ibid., XI. 200; XIV. 345.

A similar experiment, in which 120 mgr. arsenic oxide were used, was completed quantitatively, and by the Berzelius-Marsh method a ring of arsenic was obtained weighing 2.8 mgr., corresponding to 4.3 mgr. As_2O_5, or 3.6% of the amount taken. This is unfortunately the only quantitative work in the paper, and I cannot place much reliance on it owing to the inaccuracy of the gravimetric Berzelius-Marsh method with such small amounts.

Pure cultures were now made of some of the moulds developed in the above experiments, and there were isolated *Penicillium glaucum*, *Aspergillum glaucum*, and *Mucor mucedo*. Cultivations were also made of *Bacillus radiciformis*, *B. prodigiosus*, *B. subtilis*, and *Sarcina lutea*. All were then cultivated separately on sterilized arsenical preparations. The odor was noticed only from *A. glaucum* and *Mucor mucedo*. The latter, being a widespread and easily cultivated mould, was selected for further experiments.

Ten Erlenmeyer flasks were fitted with two-holed rubber corks and two right-angled tubes, one passing to the bottom of the flask, the other to just below the cork, each outer end being plugged with cotton wool. Potato pulp containing arsenious oxide and a little tartaric acid was placed in the flasks, which were sterilized, inoculated with a pure culture of mucedo in agar, and connected in series. In the rear was placed a wash bottle of water, in front a 5% solution of argentic nitrate, and a Bunsen pump drew air through the system. The temperature was that of ordinary summer heat. After 28 days the presence of arsenic was established in the filtered solution.

The solution before filtration contained a considerable quantity of a yellow crystalline substance which quickly darkened. This Gosio evidently hoped to connect with the compound $3\,AgNO_3 . AsAg_3$ of Poleck and Thümmel,* overlooking the fact that the latter is formed only in very concentrated solution. On testing the substance no arsenic was found.

The activity of *Mucor mucedo* was further shown by varying the methods of culture, the nutritive soil, and the quality and quantity of the arsenic compounds. Scheele's and Schweinfurth green, in proportions varying from 0.001 to 0.1% of the pulp, gave reactions, but realgar and orpiment gave no odor. Yet, if the action on the sulphides was protracted through many months, there was a slight development. After chemical analysis had confirmed the odor, the latter alone was considered a sufficient indication of arsenic in most of the succeeding experiments. To try the action on paper, a tight box was lined with sterilized paper colored by Schweinfurth green and fastened by sterilized starch paste which had been inoculated with mucedo. Air was drawn through the box for 39 days into argentic nitrate which then gave a positive test for arsenic.

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* Archiv d. Pharm., CCXXII. 8.

The sensibility of the mucedo varies with different conditions: humidity, amount of oxygen present (the formation of gas ceases if air be lacking), and the quantity and quality of the arsenic compounds. The best results were obtained in ground containing 0.01 to 0.05% of substance, while 4 to 5% distinctly retarded the growth. Arsenic acid, arseniates, or alkaline arsenites gave the best results. There can be a tolerance for high doses established, however, if the mould is habituated to a progressive increase. The action goes on better in solid ground than in liquid, and the best nutritive material is a carbohydrate. In albuminoid matter there was but little action, whereas in a mixture of albumen and glucose, it was intense. Whenever the mucedo showed intolerance, other moulds grew which do not decompose arsenical matter, e. g. *P. glaucum.* This explains the failure of other observers (including myself), who used large amounts of arsenic and yet obtained a quantity of mould.

The action of other moulds was examined in the same way, but it was necessary in certain cases to lessen the amount of arsenic. By this means a mould corresponding to the properties of *Aspergillum virens* was found to react. Very slight effects were obtained from *Sterigmatocystis ochracea*, *Cephalothecium roseum*, and *Mucor ramosus.* Finally, from a piece of carrot left in the open air, a new mould was isolated which proved to be identical with the *Penicillium brevicaule* discovered by Saccardo on decaying paper. Experiments on this mould showed it to be capable of more intense action than any other. With milk culture Gosio claims to recognize the odor from 0.02 mgr. of sodic arsenite and thinks it may be still more delicate. In the experiments with *P. brevicaule*, the absorbent was an acid solution of potassic permanganate, but the strength as well as the subsequent treatment is not given. The extreme sensibility of this mould led Gosio to propose its use as a means of testing for arsenic in toxicological work, and the second of his papers is devoted to the working out of this method.

The power of decomposing arsenical organic matter is proposed as a means of distinguishing between two moulds of similar properties.

As "arsenio-bacteria" Gosio specifies those which have a prompt, intense, and lasting action. He thinks that all micro-organisms may have a slight action in the course of months or years, being led to this conclusion partly by Hamberg's work, though he has no data of his own to prove the theory.

The investigation of the chemical nature of the volatile compound was begun on the assumption that arseniuretted hydrogen was formed, as the silver solution was reduced and arsenic found in the solution. On attempting, however, to precipitate argentic arsenite from solution by ammonia, it was found that the excess of alkali liberated a volatile substance with an *intense garlic odor*. The following examination was then made. The filtered silver solution was treated with excess of potassic hydroxide in a flask, and the product of the action led over lime and caustic potash to free it from carbon dioxide. The gas then passed over hot cupric oxide and the combustion product, led into baric hydroxide, caused a turbidity. The residue in the cupric oxide tube was digested for two days in cold dilute potassic hydroxide, filtered and washed. The solution was precipitated by sulphuretted hydrogen and the filtrate acidified with hydrochloric acid. The precipitate from the latter oxidized with nitric acid gave reactions for arsenic in the Marsh apparatus. We shall have to take it for granted in the above experiments that the carbon dioxide was all held back by the absorbents, and that the cupric oxide was non-arsenical.

Another filtered silver solution was made alkaline with potassic hydroxide, and air passed from it into platinic chloride for two days. The air from a series of flasks was also passed into this absorbent for ten days. In both cases no satisfactory results were obtained.

In the solution after treatment with alkali, arsenic was looked for, but only faint traces were found. This would be against the formation of arseniuretted hydrogen, yet Gosio inclines to the belief that there may be traces of it formed.

Considerable space is given to discussing the mechanism of the reaction, yet, in view of the fact that the compound has not been isolated, such discussion is purely speculative. Gosio refers to the work of Pollaci,* Selmi,† and Fitz and Mayer ‡ on the formation of hydrogen by action of lower organisms, and quotes the statement of Nencki § that bacteria may decompose water into H and OH, which would cause a hydrogenization and a hydroxylization, a double action which he evidently thinks may take place in this case, giving rise to arseniuretted hydrogen and an arsenical compound of carbon with the hydroxyl group. On the other hand, he refers to the work of Missaghi,* which opposes the formation of hydrogen by moulds.

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* Reference not given by Gosio.

† Presumably the same reference as given by me above.

‡ Ber. d. deutsch. chem. Gesells., XI. 1880; XII. 474.

§ Ibid., XII. 474.

The second paper† of Gosio need be referred to very briefly. The action of *P. brevicaule* proved so sensitive as to suggest a very delicate method for the detection of arsenic in presence of large amounts of organic matter. The method is carried out as follows. A test-tube is constricted about 20-30 mm. from its lower end, and the bulb thus formed filled with moist cotton wool. A strip of paper is cut in halves and the suspected substance placed between the slices, which are then put into the test-tube and sterilized. Inoculation is then made, and in a day or two the characteristic odor is developed. The temperature is best about 37°. Should further proof be desired, a rubber stopper with right-angled tubes may be inserted in the test-tube, and air drawn slowly through it into a sulphuric acid solution of potassic permanganate kept at 60 to 70°. This solution after proper treatment is introduced into the Marsh flask.

Undoubtedly in cases where the amount of arsenic is very small, and in contact with a large amount of organic matter, this method would be excellent, but I cannot see that in general medico-legal work it has any advantage over the common methods, particularly as it requires much time and cannot be made quantitative. It is simply a very interesting micro-biological method. The exceedingly great delicacy claimed for it (1 part of sodic arsenite in 1,000,000 being detected in a milk culture) is not surprising when we consider the amount of substance that can be recognized by the sense of smell, E. Fischer and Penzoldt,‡ for instance, claiming to have detected one four hundred and sixty millionth of a milligram of mercaptan.

The correctness of Gosio's work is unquestionable, and to him is due the credit of settling this much vexed question. Yet it seemed to me that the importance of the matter demanded a substantiation of his results by repetition of his work, particularly as so many observers beside myself had obtained opposite results, and would be better satisfied to know that the action of the moulds had been confirmed by another investigator in another country. I have therefore made some experiments similar both to those of my first series and to those of Gosio, using the material from the culture tubes sent me by him, which were five in number and contained *P. brevicaule* in potato strips to which had been added different preparations of arsenic.

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* Gazz. chim. Ital., V. 419.

† "Sul Riconoscimento dell' Arsenico per Mezzo di alcune Muffe," Roma, 1892.

‡ Ann d. Phys. u. d. Chem., CCXXXIX. 131.

SECOND SERIES OF EXPERIMENTS, USING P. BREVICAULE.

Experiment 15. — One gram arsenious oxide was mixed in a litre flask with flour and water which, without sterilization, was inoculated from the tube marked "patata esente di arsenico." A similar system of tubes to that described in Exp. 3 was attached to this flask, including the usual absorption bottles filled with 2% argentic nitrate, and air was drawn through the system for about two weeks, during which time the formation of mould was abundant and fermentation marked. The reduction of the silver solution was slight. On opening the flask no odor was noticed except that characteristic of mould. Although there was little evidence of the formation of a volatile compound, the silver solution was tested in a similar manner to that described in Exp. 1, but with entirely negative result.

Experiment 16. — One gram arsenious oxide was mixed with unsterilized flour paste, and, after inoculation with the same preparation as in Exp. 15, smeared on a large sheet of filter paper. This was placed in a bell jar over a ground-glass plate, and the jar fitted with a system of tubes and absorbents similar to that described in Exp. 4. Air was drawn through for about two weeks. The formation of mould was abundant, but no alliaceous odor was observed. The silver solution was but slightly reduced and gave no test for arsenic.

In these two experiments, the *P. brevicaule* could not tolerate the amount of arsenic under the conditions as well as the common moulds, hence the latter flourished to the entire exclusion of the former. This was shown by Mr. Roscoe Pound, of Lincoln, Nebraska, who very kindly examined the sheet in Exp. 16 and found the only Penicillium present to be *P. crustaceum*.

The conditions of Exps. 15 and 16 are not unlike those of the previous negative experiments.

Experiment 17 *a*. — In this the method of Gosio was quite closely followed. Three 250 c. c. Erlenmeyer flasks were fitted with rubber stoppers through which passed two right-angled tubes, one reaching nearly to the bottom of the flask, the other to just below the cork. The outer end of each tube was plugged with cotton wool. Sufficient potato pulp was placed in each flask to make a layer of about half an inch, and it was moistened with a solution of sodic arseniate containing about 0.5 gram to 100 c. c. Each flask contained about 100 mgr.

As_2O_5. They were then heated for two hours in a steam sterilizer and allowed to stand 24 hours. This was twice repeated. Each flask was then inoculated with a sterilized platinum point from the tube marked "patata bagnata in una soluzione di As_2O_5." The three flasks were then connected together and in the rear was joined a side-neck test-tube containing 2% argentic nitrate. In front was placed an additional layer of cotton wool in a chloride of calcium tube, then two silver solutions of the same strength as the first. The joints of the apparatus were wired and were tight. A current of air was drawn very slowly through the system day and night, the amount being measured. In one day the growth at the points of inoculation began, and in three days there was a patch half an inch in diameter around each spot. The silver solution had darkened slightly. The temperature during the trial was about 25°.

At the end of twelve days, as it became necessary to change the place of experiment, the flasks were disconnected and packed for transportation. Up to this time no difference could be noted between this experiment and the many preceding, except that the mould was in smaller quantity and apparently more homogeneous. The first silver solution was somewhat reduced, there being a slight black deposit, but the second was not changed. But as soon as the flasks were disconnected (they were not uncorked) an alliaceous odor could plainly be perceived at the tubes, *a point that I had never observed in any previous experiment.* The silver solutions were then tested, the method being for certain special reasons slightly modified. The unfiltered solution was precipitated by a very slight excess of sodic chloride, and the filtrate evaporated with sulphuric acid until it fumed strongly. The diluted residue was boiled with a very little sodic sulphite, and the excess of sulphur dioxide expelled. The cooled solution was then introduced into the Marsh flask which had been running one hour without sign of a mirror in the deposition tube. Here may it be said that all reagents used had been subjected to the most rigid test, the stream of hydrogen from the generator not giving any arsenic whatever in a seven-hour run. Twenty-five minutes after introduction of the prepared solution a clearly defined mirror of arsenic was deposited *which was the first that I had obtained in my experiments on this subject.* The amount was small, about 0.01 mgr., but, taken in connection with the odor, it was very satisfactory considering the small amount of mould and the duration of its action. One hundred and five litres of air had been drawn through. The second silver solution treated in precisely the same way gave no mirror.

b. Three weeks elapsed before the experiment could be continued, during which time the flasks remained sealed by the cotton wool. In two of them the growth did not seem to have increased much, but in the third the ground was completely filled with mould, which did not seem, however, to be entirely homogeneous. I am not sure that the stopper of this flask may not have been slightly loosened. The odor of garlic was very strong.

The flasks were connected with silver solutions as before, and air led through each day for 17 days. In four days there appeared on the lower end of the entrance tube of the first silver solution a dark mirror, which increased slightly and was *apparently* the only deposit formed. The temperature during the first week was about 20°, but afterwards about 25°. At a very rough estimate 170 litres of air were passed through the system.

The first silver solution was poured out of the bottle, and the latter merely rinsed with water. The solution was heated nearly to boiling, and excess of hydrochloric acid was added. At this point I was struck by the strong odor coming from the warm mixture, it being noticeable at a distance of two feet from the beaker. It strongly resembled the garlic odor of arsenic, and also recalled the odor from a solution of iron in dilute acid. My assistant, in making the previous precipitation with sodic chloride, noticed no odor. The odor grew weaker as the mixture was kept warm, but the argentic chloride was filtered before it had entirely disappeared. The filtrate, after addition of a little more nitric acid, was evaporated with sulphuric acid to fuming, diluted, and added to the Marsh flask which had been running for forty minutes without a trace of arsenic. In ten minutes a mirror began to appear, was very heavy in thirty minutes, and at its maximum in fifty. It was clear and well defined, but too heavy for accurate estimation. I placed it at 0.07 mgr., which is a low estimate.

Besides the mirror of silver (?) on the end of the tube in the absorption bottle, there was evident on closer inspection a small amount of a nearly colorless (perhaps slightly yellow) gelatinous-looking substance adhering to the bottom and walls of the bottle. This dissolved easily in the few drops of strong nitric acid added to dislodge the heavier black deposit, though the action of the acid upon it was masked by the nitrous fumes from the solution of the mirror. The solution was precipitated with hydrochloric acid, evaporated to fuming with sulphuric acid, diluted, and added to a Marsh flask which had been running for 30 minutes without evidence of arsenic. A mirror appeared in 30 minutes which was at its maximum in 60. The amount formed was 0.025 mgr., making 0.095, or probably 0.1 mgr. in all, from this solution.

It was possible that the first silver solution had not absorbed all the volatile compound, as was conjectured in Hamberg's case. Bearing in mind the probable volatilization of arsenic in the method employed in the first solution, the second, which contained little or no deposit, was evaporated with considerable nitric acid to incipient fusion, during which no alliaceous odor was noticed. The residue was taken up with dilute nitric acid, precipitated with hydrochloric acid, and the filtrate, after evaporation with sulphuric acid and dilution, added to a Marsh flask in which the absence of arsenic had been shown by a 40-minute run. After an hour, the mirror, which appeared slowly, was at its maximum, and was estimated at 0.015 mgr. This shows conclusively that argentic nitrate in such dilution does not absorb the volatile compound with any degree of completeness.

To prove that no arsenic could have entered from the air of the room, the rear solution of silver was treated in the same manner, and gave no trace of arsenic.

The total amount of arsenic (as As_2O_3) obtained from this series of flasks was 0.12 mgr. No further satisfactory quantitative result can be adduced for many reasons. During the interval between Exps. 17 *a* and 17 *b*, much of the compound may have escaped; the silver solutions did not absorb all of the compound, and the method of treating the first solution at least was incorrect, being based on the old assumption that arseniuretted hydrogen was the product. Hence 0.12 mgr. does not represent by any means what may have been formed. Yet if one reckons 300 mgr. of arsenic (as As_2O_3) to the flasks, the amount recovered is 0.04% of this, a proportion which for all we know may be 100 times too small.

The flasks were now uncorked. The odor, though fainter, was distinctly perceptible and was confirmed by others in the laboratory. Dr. W. G. Farlow has had the kindness to examine the growth for me, and reports that the first two flasks contained only *P. brevicaule* "fruiting and in good condition," while the third, which I suspected was not homogeneous, contained also *P. glaucum*, though the amount "as compared with the *P. brevicaule* is less than one would suppose on looking at the flask without examining microscopically."

Though the above experiment confirmed the results of Gosio to my complete satisfaction, the following trial is of great interest on account of the small amount of arsenic and its source.

Experiment 18. — Three 200 c.c. Erlenmeyer flasks were fitted as in Exp. 17, with rubber stoppers and tubes, the latter plugged with cotton wool. A wall paper was selected having 115 mgr. arsenious oxide per square meter, the color, a dark red, suggesting an aniline compound mordanted with an arseniate. 3 square decimeters of this were cut into strips and placed between several slices of potato, which were put into each flask. The total amount of arsenic used was 3.45 mgr., reckoned as As_2O_3. The flasks, after addition of a little water, were sterilized for two and a half hours at 100–105°, and showed no evidence of mould for six days afterward. The potato, which was still moist and impregnated with the red coloring matter, was then inoculated with the culture in the tube marked "patata contenente una striscia di tappezzeria arsenicale," and the flasks were connected with a series of absorbents similar to that of Exp. 17. The current of air was not drawn through the system until the flasks had stood for a week, the temperature being from 20 to 25°. No mould appeared for four days, and the growth was then very slow, was confined to the first two flasks, and the amount was very small. Indeed, after 17 days had passed without much apparent action, the silver solution being but slightly affected, I disconnected the flasks, not intending to pursue the experiment further. Yet on opening the flasks the alliaceous odor though faint, was perfectly plain, and I proceeded to test the first silver solution. This was poured out, and the very slight deposit removed with a little nitric acid was added to the solution. The latter was evaporated with nitric acid nearly to fusion, taken up with dilute nitric acid, desilverized, and prepared as usual for the Marsh flask. This had been in action 40 minutes, and was free from arsenic. At the end of an hour after introducing the solution there was a small but perfectly plain mirror, which I estimated at 0.005 mgr. The second silver solution was not examined.

Dr. Farlow kindly examined the first flask of the series, and found "*P. brevicaule* in good condition but not pure, for there was another species of Penicillium present not in very good fruit. The second species may have been a small form of *P. glaucum*, but I do not think I can say certainly from the material examined, which was too young."

The amount of the volatile compound determined in this experiment is 0.14% of the total present. This estimate is more accurate than in Exp. 17, and the chief error is in the absorbent, though the amount is only a part of what might have been formed in the course of time.

The reagents used in Exps. 17 *b* and 18, being in another laboratory, were subjected to the same rigid tests, and the absence of arsenic was proved. The dishes and utensils were proved free by blank tests.

DISCUSSION.

The scope of this paper has gone far beyond my original intention, which, as stated above, was simply to repeat the work of Fleck and of Hamberg. As the important results of Hamberg and of Gosio have not been given the publicity due to them, not to speak of the comparative obscurity into which the work of many of the other investigators has fallen, I feel that the somewhat protracted review of the work that I have here presented will make the subject clearer, and will serve to place more surely beyond cavil the fact that a gaseous or volatile compound of arsenic may be generated from decaying arsenical matter; hence the possibility of chronic poisoning from the presence of such a compound in the air of rooms papered with arsenical paper.

Of the experiments mentioned in the historical sketch, those of Schmidt and Bretschneider, Fleck, Hamberg, Selmi, Bischoff, Giglioli, and Kinnicutt are the most important. The others need not be considered, either because there was little or no chance in them for decomposition by mould, or on account of imperfect methods of experimentation or analysis. In the cases of Hamberg and Bischoff there was undoubtedly a volatile compound formed, though Hamberg proved it and Bischoff did not. Fleck and Selmi do not show conclusively that it was present.

The adverse results of the other four investigators, as well as those of my first series, are very easily explained. There was either too much arsenic for the arsenio-bacteria to tolerate, or else the latter were not present. It is worthy of note that, with the exception of Hamberg's experiments, whenever the unsterilized matter was allowed to decompose in a closed vessel, no arsenical compound was evolved, while exposure to spontaneous inoculation in the air developed an odor. This would seem to point to a tolerance when fresh germs can gain access to the material. In my own case I am inclined to think that absence of the specific bacteria was the chief reason for failure, though in many cases I used large amounts of arsenic. As to my experiments on the air of rooms, it is quite possible to explain the negative results by the choice of reagents and the amount of air aspirated. We have, however, sufficient evidence from Hamberg on this point.

The conditions necessary for the action of the moulds, especially the amount of arsenic and the quality of the culture ground, explain why the action has not been earlier discovered. Though it is not certain but that many moulds decompose arsenical matter, yet the intense action is thus far confined to four, *Penicillium brevicaule, Mucor mucedo, Aspergillum glaucum*, and *Aspergillum virens*. Further research may succeed in finding others. It is worthy of note that the most active mould is that which was discovered on decaying paper, and it must not be forgotten that a small amount of arsenic in a wall paper may be quite as good a source of the volatile compound as a very large amount.

I have not made any investigation into the nature of the compound, as such work would be trespassing on Gosio's field. I think the chances are that no arseniuretted hydrogen is formed, but that we have to deal solely with an organic compound of arsenic. This may perhaps form a "molecular" compound with the argentic nitrate, which, when the latter is acted on by hydrochloric acid or an alkali is set free. The odor of the solution was noticed by Hamberg, Gosio, and myself. Hamberg does not say whether it appeared after adding hydrochloric acid or in neutral solution. Gosio obtained it on adding alkali, and did not apparently detect it in the acid solution, while I discovered it in the desilverizing. Hamberg's yellow deposit may be identical with that noticed by Gosio and me, although Gosio does not agree with us in the finding of arsenic.

Hamberg and Gosio infer that the dilute argentic nitrate solutions absorbed only a part of the compound, and my experiments confirm this inference. Potassic permanganate probably oxidizes it completely. The non-absorption of the silver solution is an argument against the compound being arseniuretted hydrogen, for I have satisfied myself by experiment that a 2% argentic nitrate solution absorbs that gas completely when in small amounts, even when the gas is very greatly diluted with air.*

The use of argentic nitrate may partially account for some of the negative results of former investigators. With such an absorbent and the use of the simple Marsh test a comparatively large amount of the compound might have escaped notice.

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* Although the argentic nitrate absorbs the arseniuretted hydrogen completely, yet when small quantities of arsenic are used, the amount recovered from the solution is rarely over 50% of the amount taken. Some rather odd results were obtained in investigating this question, the consideration of which is reserved for another paper.

In considering the nature of the compound, the only definite facts obtained are that it is formed in presence of oxygen, that the development is best from carbohydrates, and that arsenious or arsenic acid and their salts are best suited to the development. The only conclusion that may be drawn is that the volatile compound is an organic derivative of arsenious or arsenic acids. Yet the properties are such that it has little resemblance to any of these derivatives thus far isolated. Much work remains to be done before the composition can be determined, and Gosio is continuing his research to that end.

In this connection the researches of Selmi [*] are interesting. From a corpse, in which the presence of arsenic was established, he isolated a ptomaine in small quantity, but the test for arsenic in it was negative. In the stomach of a hog,[†] saturated with an arsenic solution and left to decompose, he was able to isolate two bodies containing arsenic. The first was obtained by distillation with steam, and had an intensely poisonous action like strychnine. The second was found in the residue from distillation, and the action of this resembled that of the ptomaines. In the urine of a dog [‡] poisoned by arsenic Selmi finds a volatile arsenic compound with tetanizing action, and considers it identical with the first of the two previously described. In no case were these compounds found in quantity sufficient to make an attempt at determining their composition. Husemann,[§] referring to Selmi's work, thinks that an arsenical ptomaine could be generated from arsenical paper and paste, yet the properties of the volatile compound and the fact that it is best formed in non-nitrogenous ground seem to be against the formation of a ptomaine from these materials.

WASHINGTON UNIVERSITY CHEMICAL LABORATORY,
Saint Louis, September, 1893.

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[*] Atti della R. Accad. dei Lincei, [3], II., June 2, 1878.

[†] Mem. d. Accad. d. Scienze, Bologna, [4], I. 299.

[‡] Ibid., [4], II. 3.

[§] Arch. d. Pharm., CCXIX. 415.

V.

ON CHRONIC ARSENICAL POISONING FROM WALL PAPERS AND FABRICS.

By Charles Robert Sanger.

Received November 9, 1893.

During the spring of 1886, while assistant in the Harvard Laboratory, several cases of chronic arsenical poisoning from wall papers were brought to my notice, as the suspected papers and fabrics were sent to me for analysis. In many cases an examination of the urine for arsenic was made, this being done under the supposition that the elimination of arsenic in cases of chronic poisoning had been well studied. I was surprised to find, however, that analyses of the urine in such cases had been comparatively rare, and that little or nothing was known at that time of the elimination of arsenic under the conditions of chronic poisoning from wall papers.

Some of the results of my work were read, by invitation, at a meeting of the South Middlesex (Massachusetts) Society for Medical Improvement in the summer of 1886, but were not published, as so much reference and analytical work remained to be done before the paper could be presented in proper form. I was then called from Cambridge, and for three or four years the completion of the paper was continually prevented by other duties. In the mean time the analysis of the urine became recognized as a necessary step in the diagnosis of chronic arsenical poisoning from wall papers, and the records of such analyses have been frequent, chief among them being the paper of Putnam,* in March, 1889. In nine of the cases cited in this article the analyses had been made by me, and were sent to Dr. Putnam at his request.

Although so much time has elapsed since my work was undertaken, and the cases, as far as the actual poisoning goes, are merely additions to the already long list, yet many facts brought out during the preparation of the paper make it still worthy of publication. Two years ago

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* Bost. Med. Surg. Journ., CXX. 235.

I was about to present the results I had so far obtained, as my negative experiments on the decomposition of arsenical organic matter by mould had enabled me, as I thought, to suggest a possible explanation of the source of wall paper poisoning, if we had to rely on arsenical dust alone as a mode of causation.

The same reasons that led to my postponing the publication of that paper have delayed the appearance of this, and the later results of the former investigation have given a far closer insight into this much vexed question.

I propose first to give the record of cases that I have found which include analytical work, then the cases that came to my notice in which analytical results on wall paper and urine may be compared, and then to discuss the cause of wall paper poisoning in the light of the chemical and biological facts brought out both by this paper and the foregoing.

I have hesitated to introduce the medical side of the cases, but have considered it necessary to the completeness of the paper. The cases are stated, however, either as I found them or as they were given to me. I have further endeavored not to venture any opinion but what might be advanced from the chemical evidence. Whatever may be said of the suggestions offered, the facts are laid before the medical profession for its information and consideration.

HISTORICAL.

Previous to 1886, the cases of chronic poisoning from wall paper in which arsenic has been found in the urine are as follows.

Lorinzer * of Vienna, in 1859, gives the following cases, the analytical work being done by Kletzinsky: —

1. A girl of seventeen had occupied for two years a room of which the walls were colored by Mitis green. The symptoms were loss of appetite, headache, nausea, unquiet sleep, pains in the shoulder, eruption in the knee joint, constipation. The patient was always pale, with sunken cheeks and dark rings under the eyes. She was removed to another room and given potassic iodide, six grains daily, with warm bath twice a week. In two months she was restored to her normal health. The urine was not examined for arsenic.

2. A woman fifty-four years old had occupied for some years a room which was found to have a paint or wash containing quantities

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* Wiener Med. Wochenschrift, 1859, Heften 43 and 44.

of arsenic and copper. In previous years, she had no especial trouble except occasional pains in shoulder joints and back, but in the winter in question these increased, and she began to lose appetite and flesh, and her health was generally bad until she went away for the summer. After her return in improved health, she continued well at first, but came down after a while with fever, with severe pain in the neck and shoulders. The latter left her with the fever, but there remained a peculiar unpleasant feeling, accompanied by pain in the abdomen. She was also troubled by insomnia, which, oddly enough, appeared to be intermittent, a sleepless night being followed by one of comparative rest. Her appetite was poor, but there was no marked symptom of digestive disturbance, and the tongue was not coated. There was dryness and burning in the throat. Constipation was marked. The spleen was not enlarged. 850 c.c. of the urine, after treatment with potassic chlorate and hydrochloric acid, were evaporated to 20 c.c., and the solution, free from chlorine, was introduced into the Marsh apparatus previously tested (time not given) for absence of arsenic. After thirty minutes, a very slight mirror was obtained, which looked like arsenic. The patient was then removed to another room and ten grains potassic iodide given daily. After ten days, the urine was analyzed again, and a much larger and more characteristic mirror was found. The iodide was continued for some time, until the patient grew better and suffered no return of the symptoms. The freedom of the urine from arsenic was not then determined.

3. A woman forty-five years old had had typhus, from which she recovered very slowly, the convalescence being retarded by certain symptoms which were inexplicable. She had no appetite and suffered great distress before meals. The tongue was, however, clean. She had pain in the head, insomnia, was irritable and peevish. Pulse normal. After the patient had been nine weeks in bed and was getting no better, the covering of the wall was analyzed, and arsenic and copper were found in quantity. Fifteen grains of potassic iodide were given daily, and, after some days, the urine was analyzed. The apparatus was carefully tested and the urine residue gave a slight but unmistakable mirror which gave reactions for arsenic. The patient was removed to another room and the iodide continued. The symptoms began to disappear, and in four weeks the patient was entirely well.

4. A girl twenty-four years old had typhus in the autumn of 1857, from which she was recovering. Pulse was normal and tongue clear. Constipation marked. Appetite did not return and patient did not recover strength, but was confined to her bed most of the time. She

was troubled by a ringing in the ears which disturbed her sleep. On removal to the country, her health improved, but on return to Vienna in the following autumn, some of the symptoms returned. There was now some nausea. The throat was red and irritated. The girl had slept for several years in the room, and had apparently not been affected by the arsenic, which was found, together with copper, in quantity on the walls. Twenty grains of potassic iodide were given, and after several days the urine was found to contain a trace of arsenic, as well as a trace of copper. The green coloring matter was removed from the walls. After continuing the doses of iodide, together with warm baths and exercise, the patient in a few weeks recovered.

5. A woman seventy-eight years old had lived for some time in a room the walls of which were colored by Mitis green, which could be easily rubbed off. In the spring of 1858 she was troubled by periodical recurrence of ringing in the ears and tightness in the head, accompanied by digestive disturbance and constipation, and a feeling of oppression in the stomach. On going to the country she became better, but on return in the autumn was necessarily confined to the house, and the symptoms returned. The ringing in the ears was intensified. There was pain in the abdomen, which was distended and painful to the touch. Pulse and respiration normal, skin dry, tongue clean. Nights sleepless and anxious. April 29, 1859, arsenic and copper were found in the urine in traces. Ten grains of potassic iodide were prescribed daily, and for the first few days the symptoms decreased. The ringing in the ears was less and the nights were better. Patient then became feverish, with dry cough and metallic taste. May 15, no arsenic or copper could be found in the urine. During the following days the metallic taste increased, and there was excessive flow of saliva. The iodide was given up and an astringent wash applied, stopping the flow of saliva. May 29, there was again no arsenic in the urine. During this time pleuritis had come on, and it developed into pneumonia, from which the patient died on June 3. Some days before death, the ringing in the ears had stopped, but there was a burning sensation in the stomach day and night, and the patient vomited mucus. The intestines and brain were examined for arsenic, but none could be detected with certainty.

In these five cases, although the details of the analyses are not given as carefully as could be desired, it is probable that a small amount of arsenic was found in the urine, though it was impossible to estimate it with the means then at hand. It is safe, however, from the description of the mirrors, to set a limit of 0.05 mgr. arsenious oxide per litre. The elimination was apparently increased by the potassic iodide, but the rate of elimination was not sufficiently studied.

Müller,* of Augsburg, in 1860, considers Kletzinsky's results to have been not well established, and gives the following cases, which are also detailed by Fabian,† who performed the analytical work.

1. Man, aged 37. Symptoms: headache, loss of appetite, excess of saliva, eructation, oppression after eating and vomiting, tongue slightly coated, constipation. Medicine gave no relief, but absence from home improved his general health. On return symptoms increased, and, in addition, patient complained of pressure on brain and dizziness. The wall paper had been sold as free from arsenic, but contained a large quantity, and the color could be easily rubbed off. Fabian predicted a negative result when asked to analyze the urine. December 13, 1859, after finding his reagents free from arsenic, he established the presence of arsenic in 912 grams of urine. He went over his reagents again with the same result, and an examination of a fresh quantity of urine showed arsenic again. The urine was treated with potassic chlorate and hydrochloric acid, evaporated, precipitated by sulphuretted hydrogen, and the precipitate thus obtained tested in the Marsh apparatus. The wall paper was removed, and potassic iodide prescribed (dose not stated). December 23, 812 grams of urine were analyzed, and a greater quantity of arsenic was found than before, the amounts in both cases being comparatively small. January 19, 1860, 912 grams of urine were found to be completely free from arsenic. This in 37 days after taking the potassic iodide. Recovery followed the removal of the paper.

2–3. A woman, aged 27, and her child, 18 months, had lived for some time in a room which was covered by a green unglazed paper, in which arsenic and copper were found. The mother complained of recurrent headache and pressure in the head. Both were extremely pale and suffered from indigestion. January 28, 720 grams of the mother's urine showed a trace of arsenic, after which the wall paper was removed and potassic iodide prescribed. February 10, 692 grams showed an increased amount. February 27, 716 grams showed a less amount, and on March 27, 62 days after taking the iodide, the complete absence of arsenic was proved.

550 grams of the child's urine, examined January 28, yielded no arsenic. This may perhaps find explanation in the fact that,

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* Wiener Wochenschrift, 1860, Heften 18, 19, 20, 21.

† Dingler, Polyt. Journ., CLVII. 212.

shortly before the examination, the physician had prescribed a powder of lactate of iron, magnesia, and phosphate of lime, which may have had some effect on the elimination. The physician did not dare to try the effect of potassic iodide, owing to the child's constitution. Both mother and child improved after the paper was removed.

This investigation is accurate, and the results reliable. It is unfortunate that no method was known to Fabian which would have permitted the determination of such small amounts of arsenic. From the description of the mirrors, I cannot place the amounts at over 0.05 mgr. per litre.

Kirschgasser,* in 1868, published twenty-one cases of chronic poisoning, chiefly from arsenical wall paint, in which are the most complete details of symptoms that have ever been presented. I need not refer to these cases at any length, as they are well known, and are commented upon especially in Dr. Putnam's paper, above referred to. I note, however, the following. The rooms were partly on the ground floor, partly on the first or second story, and were not damp, though some were badly aired. There was no apparent opportunity for miasma. Occasionally a garlic odor was observed. The children appeared less affected than the elders. In one case, the intermittent character of the symptoms noticed by Lorinzer † was confirmed.

The urine was examined in eight of the cases, with a positive result in six. In one of the two negative tests the urine was not collected until six weeks after the removal of the arsenical color. The work was done very carefully by Holthof. Large amounts of urine (6 to 18 pounds, and in one case 25 pounds) were taken, and the reagents examined in quantities larger than would be used in one analysis. The method of analysis in seven of the cases was as follows. The urine was acidified with hydrochloric acid, and sulphuretted hydrogen was led in for eight days, occasionally warming. The precipitate was collected on a filter, dried, removed from the filter, and evaporated repeatedly with nitric acid. The acid was neutralized by sodic carbonate, and the solution evaporated and melted to destroy all organic matter. The sodic nitrate was then decomposed by sulphuric acid, and the clear solution put into the Marsh apparatus. The reduction tube was heated for 30 minutes, and the mirror examined for arsenic. In the eighth analysis, 25 pounds of urine were acidified with nitric acid and evaporated to dryness on the water bath. The residue was treated with fuming nitric acid and heated until the mass melted quietly, after which it was dissolved in a little water, filtered, and the filtrate heated with excess of sulphuric acid until the nitric acid was expelled. The diluted acid solution was then added to the Marsh apparatus and gave no mirror in 30 minutes. After establishing the absence of arsenic in the urine of the case where six weeks had elapsed before collection of the urine, an analysis was made, two weeks later, of ten pounds of fæces. These were heated two days with dilute potassic hydroxide, and chlorine led in. The brown mixture was decanted from the sediment, saturated with hydrochloric acid, and chlorine passed until quite clear. After driving out excess of chlorine, the solution was treated with sulphuretted hydrogen, and thereafter as in the urine analyses. A heavy mirror was obtained. This is interesting as showing the elimination by the fæces after the elimination by the urine had ceased.

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* Vierteljahr. f. gericht. Med., N. F., IX. 96.

† *Loc. cit.*

In no other case, however, was there any attempt to show elimination of the arsenic, on removal of the cause of poisoning and cessation of the symptoms. The results of the analyses agree with those of Kletzinsky and Fabian in that only small quantities of arsenic were found. The quantitative determination was impossible as before.

Clarke,* in 1873, gives the case of a woman living in a badly ventilated room papered with a highly arsenical paper, who had symptoms which he said might be attributed to a mild case of typhoid fever; great prostration, headache, wakefulness, great nervous excitement, irritable stomach, and coated tongue. An analyst found the dust of the room to contain about 0.2% of arsenic, and in 48 oz. (1,700 c. c.) of urine he obtained 0.26 grain (16.8 mgr.). The sputa contained a trace. Unfortunately, the method of analysis is not given, and we have no means of accounting for the great difference between this amount of arsenic (9.2 mgr. per litre) and the amounts in all the other cases we have to deal with. Yet, in the ordinary quantitative methods, which were the only ones available, 16.8 mgr. is a small amount to determine accurately, and it is quite possible that a serious error was made. This view is supported by the amount of arsenic found in the dust, which is, comparatively, very large.

On removal, the patient grew better, but no further test of the urine was made.

Mörner,† in 1876, gives some analyses of urine which are open to criticism from the method of analysis used. In one case, the wall papers were in several layers, all containing arsenic, the inner more than the outer. The reagents were all tested by a run of 45 minutes, but gave no mirror resembling arsenic. In the first case, four litres of urine were treated with potassic chlorate and hydrochloric acid, but, as the destruction of the organic matter was slow, Schneider's method of distillation with salt and sulphuric acid was resorted to, though no attempt was made, apparently, to reduce the arsenic acid before distillation. The distillate was precipitated by sulphuretted hydrogen, and the precipitate dissolved in ammonia. One half of this solution was evaporated, and the residue examined, according to Fresenius and Babo, by mixing with sodic carbonate and potassic cyanide, and heating in a stream of carbon dioxide. A white mirror was obtained, which on refusion and reheating gave a dark mirror, partially soluble in sodic hypochlorite. In another case, Mörner obtained a "large" mirror. The patient in whose urine this was found went into a room containing no arsenic, and one month later there was no arsenic in the urine. Two other cases gave "smaller" mirrors, another a "doubtful," and in one case there was none. In the urine of people living in rooms containing no arsenic, there was no arsenic found. All the analyses after the first were made by Schneider's method directly.

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* British Med. Journ., June 21, 1873.

† Upsala läkarefören. Forhand., XI. 527; also, ref., Virchow-Hirsch, Jahresb., XI. 405.

One cannot help, on reading Mörner's paper, distrusting the results obtained, as the course of analysis would not only allow arsenic to creep in, but might result in the loss of arsenic, if not carefully conducted. As W. Fresenius * has shown, the Fresenius-Babo method is capable of very delicate work in careful hands, but, in general, it does not give as good results as the Berzelius-Marsh.

Jolin,† in 1880, gives the case of a man occupying a badly ventilated room with an arsenical wall paper, who suffered from recurrent gastric catarrh, conjunctivitis, and great weariness. The urine was treated with potassic chlorate and hydrochloric acid, and evaporated to dryness on the water bath. Potassic nitrate was then added, and the mass warmed with sulphuric acid until nitrous fumes ceased. Into the solution was then passed sulphuretted hydrogen (from calcic sulphide and hydrochloric acid), and the resulting precipitate eventually introduced into the Marsh apparatus. A mirror was obtained 2 cm. long, equally translucent over the entire length, and was judged to be between 0.05 and 0.01 mgr. The reagents were care-

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* Fresen. Zeitschr., XX. 522.

† Hygeia, Stockholm, XLII. 235.

fully tested, but no mirror resembling arsenic was obtained. Jolin regrets that the amount could not be accurately estimated, but the approximation is probably quite near the correct amount. It is to be regretted that such a long method of treatment was used, as the addition of unnecessary reagents adds to the chances of error.

Welander,* in 1880, reports the case of a man and wife who had been for some time depressed and out of health, especially the woman, who suffered from gastric catarrh. She lost appetite, and became emaciated. Complained of a disagreeable garlic taste, and even imagined that the urine smelled of garlic.† Her depression increased to such an extent that she became hysterical. The papers and hangings were found to be arsenical and were removed, and four days afterward 1,500 grams urine were examined. This was evaporated to the consistency of syrup on the water bath, fuming nitric acid and sulphuric acid were added, and the whole heated on the water bath for twelve hours. The solution was then filtered, and the filtrate saturated with sulphuretted hydrogen (from calcic sulphide and hydrochloric acid) for twelve hours. The precipitate was charred with sulphuric and nitric acids, and the extract added to the Marsh apparatus. After some hours (*sic*) a mirror of arsenic was obtained, mixed with some sulphur. After the removal of the papers, the patient recovered, and, some weeks after, the urine was found to be free from arsenic.

The length of time which elapsed before the mirror appeared renders the result somewhat doubtful, unless there was organic matter or a large quantity of nitric acid in the extract, in which case the reduction of the arsenic would have been retarded. Yet Welander does not say that the reagents received the same long test to assure their freedom from arsenic.

Kjellberg,‡ in 1881, gives the case of a healthy woman, who suffered during the winter of 1878–79 from headache, loss of appetite, and frequent diarrhœa. The wall paper was found to be arsenical. In the summer of 1879 she was restored to health by a journey, and came back to a new house. As the symptoms returned, the surroundings were examined, and the mattress cover was found to contain arsenic. Arsenic was found in the urine, but two months after recovery it was absent.

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* Hygeia, XLII. 238.

† This may, of course, be purely imaginary, but one is reminded of Selmi's claim (see previous paper, page 147) of the discovery of a volatile arsine in the urine of a dog poisoned by arsenic.

‡ Hygeia, XLIII. 456; ref., Virchow-Hirsch, Jahresb., XVII. 398.

Reichardt,[*] in 1883, mentions a case in which a certain room had been covered for twenty years with a slightly arsenical paper. The occupant had felt no ill effects, but on calcimining over the paper with a green, which proved to contain a quantity of arsenic, symptoms were felt which were attributable to arsenical poisoning. The calcimining was done in damp autumn weather, and the room was used as a work-room until late at night. A garlic odor was noticed. The urine, slightly acidified with nitric acid, was treated with sulphuretted hydrogen for 24 hours, and the resulting precipitate eventually introduced into a Marsh reduction flask. By a method proposed by Reichardt [†] himself, the gas from the flask was led into argentic nitrate. The latter was then treated with bromine water, the argentic bromide filtered off, and the arsenic acid in the filtrate precipitated by magnesia mixture. A precipitate of ammonio-magnesic arseniate could be detected, but not in sufficient amount to estimate. It must, however, have been less than a milligram, as Reichardt claims to be able to determine that amount by his method.

I am unable to find any other detailed cases in which arsenic was found in the urine up to the beginning of my own work in 1886, although Wood [‡] mentions the fact that he found arsenic in the urine in a case of wall paper poisoning, and I do not know that others had not done the same. In none of the cases, except that of Clarke, has there been any quantitative analysis possible. Yet, with this same exception, the amounts found have been exceedingly small, and in this respect confirm the results obtained by me.

CASES AND ANALYTICAL WORK.

From the results above and my own, it is evident that the amount of arsenic to be looked for in the urine is very small; hence the method of analysis becomes of the greatest importance. Every one knows the wide distribution of arsenic, and unless we can, by the utmost care, shut out the possibility of its getting into our analysis, except through the urine, the value of the analysis is nothing. Not only must the reagents be most carefully tested in quantity greater than likely to be used, but as few reagents as possible must be employed. Dishes and other utensils must be scrupulously clean.

The treatment of the urine in the cases below was as follows. To a measured quantity was added about one tenth of the amount of concentrated nitric acid, and the whole evaporated to dryness over a free flame. As the mass nears dryness, the flame is lowered. More acid may be added if necessary, care being taken to have an excess, in order to avoid carbonization of the mass at the end. Deflagration often ensues, but loss of arsenic is not to be feared in presence of an excess of nitric acid. The organic matter is nearly all destroyed by this treatment, but, to eliminate all, the residue is transferred to a smaller dish, a little more nitric acid and strong sulphuric acid are added, and the whole heated until a clear white melt is obtained, which fumes strongly. After cooling, water is added, and the contents of the dish added to the reduction flask of the Marsh apparatus. The detection and determination of the arsenic are conducted by a modification of the Berzelius-Marsh method, published by me two years ago.* It is only by such an optometric process that the extremely small amounts of arsenic can be quantitatively estimated, the principle of the modification being the comparison of the mirrors with those obtained from definite amounts of a standard solution of arsenious oxide.

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[*] Archiv d. Pharm., [3], XXI. 271.

[†] Ibid., [3], XVII. 291.

[‡] Mass. State Board of Health Report, 1884.

Thus the reagents used are sulphuric acid, zinc, distilled water, and nitric acid, all of which have been repeatedly tested in larger quantities than would be used in one analysis. The utensils: evaporating dishes of Berlin porcelain, stirring rods, funnels, beakers, and measuring cylinders have been used for this purpose alone. The filter paper has been tested in quantity. Fearing that the glaze of the dishes might contain arsenic, and that the glaze would be dissolved by the acid sulphates, I kept a quantity of melted acid potassic sulphate in a dish for some time, stirring also with the glass rod used. No arsenic was found in the solution, showing that there was no danger from this source. Finally, blank trials with non-arsenical urine, conducted exactly like the others, confirmed the purity of the reagents and the cleanliness of the utensils. In collecting samples of urine, care has been taken to guard against accidental introduction of arsenic from unclean bottles.

The reduction tube of the apparatus is drawn out so as to give two heating places. Before introducing the solution to be tested, the apparatus is run for one hour with the lamp under the first heating place, and the absence of arsenic in the apparatus fully determined. One half, or any aliquot part, of the solution is then added. After 30 minutes, the lamp is moved back to the second heating place, the rest of the solution added, and the heat maintained for 30 to 60 minutes longer. Of the two mirrors thus obtained, one has been used to confirm the presence of arsenic by solution in sodic hypochlorite, or, when possible, by the odor on heating, while the second has been retained for reference. In case the amount of arsenic is too small to divide, the whole may be collected in one mirror.

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* These Proceedings, XXVI. 24.

I have found the careful destruction of the organic matter to be necessary, as a comparatively small quantity of organic matter in the reduction flask is of decided hindrance to the reduction of the arsenic and deposition of the mirror. That this is the case seems to be the general opinion, although Chittenden and Donaldson* state that their results are not affected by the presence of organic matter. They were able to recover from 50 c. c. urine, introduced into the flask directly with a few drops of olive oil to prevent frothing, the original amount of arsenic added, besides getting a distinct mirror from 0.01 mgr. It would, however, be impossible to work with the concentrated solution of a large quantity of urine without destroying the organic matter partially, and I have taken the precaution to destroy it thoroughly, particularly as the use of the method as a quantitative one depends on the uniformity of deposit of the arsenic mirror, and this cannot be assured in the presence of organic matter.

The cases in which the analytical work fell to me are as follows: —

Case 1. In the autumn of 1883, Mr. A. and wife took a house in Cambridge, of which four rooms, parlor, dining-room, study, and bedroom had been recently papered. In the spring of 1885 the halls of the house were covered, and either in 1883 or 1885 the other rooms. These papers contained the following amounts of arsenic calculated as arsenious oxide.

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* Amer. Chem. Journ., II. No. 4.

	Mgr. per Sq. Meter.	Grains per Sq. Yard.
Parlor.	64.9	0.830
Hall.	104.5	1.340
" border.	Very large amount,	not estimated.
Dining-room.	479.0	6.130
Bedroom walls.	96.1	1.230
" ceiling.	1.0	0.013
Study walls.	255.0	3.260
" ceiling.	3.0	0.040
" border.	153.1	1.960
Another bedroom, walls.	0.0	0.000
" " ceiling.	2.0	0.026
" " " border.	596.0	7.630
" " wall "	115.4	1.480
" " frieze.	552.6	7.130
Servants room.	72.8	0 940
Storeroom.	25.2	0.330

The rear hall and bathroom contained small amounts, and were not quantitatively examined. For several months after taking the house no trouble was experienced, but toward the summer of 1884 Mr. A. and his wife, together with a gentleman who occupied the house with them, began to feel some discomfort. This disappeared during the absence of the family from the house in the summer, but began again soon after they returned in the autumn. The plumbing was in good condition and the furnace was a new one. From the fact that the discomfort was worse when the latter was in action, the source of the trouble was attributed to it. No immediate increase of the symptoms followed the papering of the halls, but the health of the family grew worse during the spring of 1885. The chief symptoms were trouble with the digestive organs and insomnia. The tongue was heavily coated, and the food seemed to "sour" in the stomach. Nausea was frequent. There was much languor and dizziness and the eyelids were badly inflamed. In July the family went away to the sea-shore, and there was marked improvement; but on going back to the house for August the symptoms appeared again, while return to the sea-shore for September brought immediate relief. In the early autumn the symptoms returned, but were not at their height until the furnace was used. This was again thoroughly overhauled and the air of the house tested for carbon monoxide with negative results. Mr. A.'s symptoms increased to a greater extent than those of the others, and were accompanied by soreness of the abdomen and abdominal pains at night.

During the last week of December, 1885, the source of the trouble was discovered by a qualitative analysis of the papers. Pending the removal of the papers, the family left the house and experienced immediate relief, especially in sleeping, but many of the symptoms continued for some time afterward. January 7, 1886, a week after leaving the house, 1,750 c.c. of Mr. A.'s urine were analyzed by the method detailed above, and contained 0.01 mgr. arsenious oxide per litre. The papers were replaced by absolutely non-arsenical paper, and the health of the family gradually came to its normal condition, although there was occasional digestive disturbance. The elimination of arsenic from the system was apparently very slow. 800 c.c. of urine, analyzed March 31 (84 days), contained about as much as before, and 820 c.c., analyzed May 26 (140 days), contained 0.007 mgr. per litre. Some time after this another sample of urine was sent to me at Annapolis, and was set aside with several others until I should find time to take up the subject again. So much time elapsed, however, before the analyses could be made, that I do not consider the results worthy of record.

Case 2. Mr. C., aged 25, had for some years slept in a large room, the paper of which contained from 10 to 15 mgr. arsenious oxide per sq. m. (0.13 to 0.20 gr. per sq. yd.). The temperature was low, and there was a good circulation of air in the room. At all events, no ill effects were felt, and the urine, examined during January, 1886, contained no arsenic. July 7, 1886, Mr. C. went to a house at the seashore and occupied a small room, of which the paper contained 146 mgr. per sq. m. (1.88 gr. per sq. yd.). The area of paper was about 22 sq. m. (26.3 sq. yd.). In addition the windows were hung with red curtains about 4 sq. m. (4.8 sq. yd.) in surface, containing 151 mgr. per sq. m. (1.95 gr. per sq. yd.). Soon after taking the room he began to suffer from indigestion with occasional bowel pains. A qualitative analysis of the paper showing arsenic, the urine was examined on July 15, and contained 0.042 mgr. per litre. Mr. C.

continued to occupy the room, but the pain in the bowels became more frequent, and on July 27 diarrhœa set in. July 28, the room was changed for one in which the paper contained 46.8 mgr. per sq. m. (0.6 gr. per sq. yd.), and on the next day Mr. C. was called away.

Returned in a day or two, and occupied the second room with marked improvement, which continued. August 3 (19 days), the urine contained 0.021 mgr. per litre. During the rest of the month there was no recurrence of indigestion except on one day, August 19. The urine of this day was collected, and a sample was also taken some time after leaving the house. Both shared the fate of those mentioned in the previous case.

Though the second room was arsenical, the apparent exemption from its effect was perhaps due to the lesser amount, perhaps to the difference in the compound of arsenic on the walls. The second room was also better aired than the first.

Case 3. Mr. D., after living in a room which contained no wall paper, removed to another house and occupied a room in which the paper, a dark red, contained 110.4 mgr. per sq. m. (1.42 gr. per sq. yd.). About a month after moving, Mr. D. began to be troubled with severe headaches, which were attributed by one physician to change of locality. These headaches continued for some weeks, and in addition there was trouble with the eyes and throat. Another physician suspecting arsenical poisoning, the paper was examined. Other papers in the house contained arsenic but were only qualitatively analyzed, and contained less than that of the room in question. February 12, 1886, the urine contained 0.015 mgr. arsenious oxide per litre. The paper was removed and a non-arsenical paper substituted. Improvement began at once, and the headaches soon disappeared. Here again was an apparently very slow elimination as on June 18 (127 days) the urine contained 0.003 mgr. per litre.

Case 4. Miss E. occupied a room with a light blue paper containing 842 mgr. per sq. m. (10.78 gr. per sq. yd). The windows were hung with blue cretonne curtains, with flowers and leaves in red, yellow, and green, containing 309 mgr. per sq. m. (3.9 gr. per sq. yd.). No symptoms of this case have been given to me except a long continued inflammation of the eyes, continual lassitude and weakness, and trouble with the throat. The patient, a girl in robust health, became weak and nervously prostrated. The urine examined March 10, 1886, contained 0.02 mgr. arsenious oxide per litre. Miss E. was sent away and rapidly improved in general health. The arsenical paper and hangings were removed and replaced by non-arsenical material. No recurrence of the symptoms was experienced on return to the house. Samples of the urine could not be obtained immediately after removal of the paper, or during convalescence, but in October the urine was free from arsenic.

Case 5. Mr. F., for six years previous to 1886, had occupied a large, dry, sunny room, and generally spent sixteen to eighteen hours each day in it. Two or three years before the report of the case, several stuffed birds and animals, preserved by the free application of arsenious oxide, were placed in the room. The wall paper contained 5.7 mgr. per sq. m. (0.073 gr. per sq. yd.), and the border 0.4 mgr. (0.005 gr.). The paper of an adjoining bedroom contained 23.1 mgr. per sq. m. (0.3 gr. per sq. yd.). The analysis of the last was made from a sample taken from the wall, with portions of an old, adhering, underlying paper. Mr. F., for nine months prior to April, 1886, "noticed perceptibly a train of nervous disturbances, as occasional attacks of dizziness and unsteadiness, a feeling of depression, and loss of muscular power. He suffered also from a constant coryza, and a dry cough. He had no gastric or intestinal disturbance." The presence of the birds suggesting a possible explanation of the symptoms, 1,500 c.c. urine were analyzed April 12, 1886, and contained 0.03 mgr. arsenious oxide per litre. The birds were removed and the walls and room cleaned, but the papers were left on the walls. April 26 (14 days) 1,350 c.c. showed 0.026 mgr. per litre. Mr. F. improved in general health after removal of the preparations, but the elimination of arsenic was apparently slow. June 1 (50 days), 1,220 c.c. gave 0.002 mgr. per litre. June 14, Mr. F. began to take five grains potassic iodide three times daily, which seemed, as in the above cases of Lorinzer and Müller, slightly to increase the elimination, as on June 21 (71 days) the amount from 1,320 c.c. was at the rate of 0.006 mgr. per litre. Yet on July 16 (96 days) there was still a trace, 1,270 c.c. giving 0.002 mgr. per litre. This is possibly explained by the presence of the wall papers, or by the fact that the carpets had not been shaken. The iodide was discontinued, and Mr. F. went away for two months, returning "feeling very well physically, the symptoms alluded to having mainly disappeared."

Case 6. This is Case 13, reported by Dr. S. W. Driver of Cambridge, in Putnam's paper.* "The case was one of severe and painful inflammation in the abdominal cavity, with constipation and loss of strength, . . . but it was difficult to say what symptoms, if any, were to be attributed to its [the arsenic] influence."

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* *Loc. cit.*

The only wall paper in the house was in the room where the patient spent a great deal of his time, and the amount was 690 mgr. per sq. m. (8.8 gr. per sq. yd.). The urine, analyzed May 18, 1886, contained 0.016 mgr. per litre, and June 16 (29 days), after removal of the paper, 0.002 mgr. per litre.

Case 7. This is one of the group reported in Putnam's paper by Dr. J. T. G. Nichols of Cambridge, but the analysis of the urine was not given. Dr. Nichols sends the following facts to me: "The girl was about four years of age. She had indigestion, constipation, and occasional vomiting. Insomnia was a marked symptom. She had frequent attacks of sore throat, and was much troubled by eczema of the vulva and anus. She was easily tired and very irritable. She did not lose flesh nor color." The wall papers were examined by Professor H. B. Hill. In the child's room was a blue frieze about six inches wide containing 710 mgr. to the sq. m. (9.09 gr. per sq. yd.). One of the other papers in the house contained 153 mgr. per sq. m. (1.96 gr. per sq. yd), another 83 mgr. (1.06 gr.), while the rest were but slightly arsenical.

April 6, 1886, 250 c.c. urine gave an amount of arsenic equivalent to 0.015 mgr. per litre. The papers were removed, and "gradual but steady improvement soon began." The elimination was slow, but I cannot say that all arsenical surroundings were removed. On June 29 (84 days), 200 c.c. urine gave 0.012 mgr. per litre, and on July 15 (100 days), 930 c.c. gave 0.008 mgr. per litre. The child had no return of the symptoms after removal of the papers.

The following cases are accompanied by analyses of the papers and a single analysis of the urine.

Case 8. This is Case 10, reported by Dr. Driver, in Putnam's paper. Patient, N. J., a girl aged 17, and her sister (Case 9), occupied a room of which the walls were covered by an old-fashioned paper, with red flowers and green leaves, and bordered with a strip of dark green two inches wide. The green was probably Scheele's or a similar one. The paper contained 116.7 mgr. per sq. m. (1.48 gr. per sq. yd.), and the border 1,200 mgr. per sq. m. (15.36 gr. per sq. yd.). The health of both girls had been impaired for two years. Dr. Driver noted to me the following in N. J.'s case: "Puffed and swollen face, reminding one of the effects of ivy poisoning, anæmia, quick pulse, 80 to 90, dizzy head, nausea, no appetite, dyspepsia. Slight trace of albumen that soon disappeared. Grew better under diuretics and tonics." The urine was analyzed May 5, 1886, and contained 0.068 mgr. per litre. On removal of the paper, recovery ensued.

Case 9. (Case 11, Driver-Putnam.) M., aged 19, sister of N. J., occupied same room, but was away from home during the day, while her sister N. remained at home, made the beds daily, and swept and dusted the room once or twice each week. Dr. Driver notes symptoms: "Dyspepsia, irritated eyes for which she went to the eye and ear infirmary, poor appetite, recurring pustules in outer meatus of ear. Would feel wretchedly for two or three days at a time." The urine, examined May 5, contained 0.028 mgr. per litre. The difference in amounts is interesting, from the fact that M. spent less time under the influence of the paper than N. did, and that she was less affected. As in the case of her sister, recovery followed the removal of the paper.

Case 10. Miss G., aged 30, occupied a small room in a seaside hotel, the paper of which contained 185 mgr. per sq. m. (2.37 gr. per sq. yd.), and the border 134 mgr. per sq. m. (1.72 gr. per sq. yd.). The areas of paper and border were, respectively, 27.7 sq. m. (33.08 sq. yd.) and 1.86 sq. m. (2.22 sq. yd.). Connecting with this room was another, on which was 23.4 sq. m. (27.95 sq. yd.) of the same paper and 1.86 sq. m. (2.22 sq. yd.) of the same border. For about a month after taking the room, the occupant was never free from indigestion. There were occasional severe pains in the bowels with constantly recurring diarrhœa. The first room had but one window and the circulation of air was poor. The occupants of the second room were apparently not affected, but it must be taken into account that this room had three windows and was well aired. The walls of both rooms were covered with a glue "size," and the symptoms soon began to abate. The urine was not obtained until six days after the size was put on. It then contained 0.054 mgr. per litre. During the rest of the summer no return of symptoms occurred except occasional slight indigestion.

Case 11. S. H., a girl aged six, had occupied for over a year a room of which the paper contained arsenic, but the amount was not determined. During the spring of 1886 the child began to show a capricious appetite, with signs of digestive disturbance. The family took a house at the seashore on July 3, and S. occupied with her brother (Case 12) a room on the lower floor, the paper of which contained 313.5 mgr. per sq. m. (4.01 gr. per sq. yd.), the border containing 128 mgr. (1.63 gr.). No other symptoms were developed, but the indigestion became more marked. August 7, 860 grams of the urine contained 0.019 mgr. per litre. On this day both children were removed to a communicating room, merely for a change, the difference in the amount of arsenic not then being established. Little or no improvement resulted. The paper in this room contained 109 mgr. per. sq. m. (1.41 gr. per sq. yd.), and the border had 24 mgr. (0.31 gr.). August 12, both rooms were sized with glue. The effect was soon noticed and the child improved rapidly.

Case 12. T. H., brother of S. H., aged four, had occupied a room which contained but a trace of arsenic in the wall paper, and on coming to the sea-shore house was perfectly well. Occupied same room as his sister (Case 11), but no signs of a similar digestive disturbance showed themselves. August 7, he was removed with his sister to the communicating room. About this time he had been playing during the day with a red flag which was afterwards found to contain 336 mgr. per sq. m. (4.08 gr. per. sq. yd.), and he kept it with him for several days. August 9, he was attacked with diarrhœa, accompanied by fever, which lasted for three days. The urine contained 0.008 mgr. per litre. August 12, as mentioned above, both rooms were glue sized, and for the rest of the summer there was no further trouble.

The other papers in the house were, with one or two exceptions, highly arsenical.

Case 13. Mr. J., a clergyman in good health, lived in a house which was papered in the spring of 1885. Three of the papers contained arsenic in considerable quantity; study, 40.6 mgr. per sq. m. (0.5 gr. per sq. yd.); bedroom, 31.2 mgr. (0.4 gr.), and the third, which I believe covered the hall, 14.4 mgr. (0.18 gr.). Not long after the rooms were papered, Mr. J. began to suffer from extreme languor and diarrhœa, for which he could discover no satisfactory cause, either in diet or daily habits. These continued until he left home for his vacation, and for six weeks he was in perfect health. On return, the symptoms came back, accompanied by insomnia, dyspepsia, and swelling of the hands and feet. Neither his local physician nor a New York physician whom he consulted could assign a cause for what seemed to them to be a case of poisoning. The analysis of the urine, February 25, 1886, showed 0.01 mgr. to the litre. The walls were stripped and the patient "treated for arsenical poisoning." Mr. J. reported his health to me afterward as being improved, but, as he was unwilling to pursue the matter further on account of publicity, the record ceases here.

Case 14. This case was reported to me by Dr. A. P. Clarke, of Cambridge, and mentioned by him at the meeting of the South Middlesex Society above referred to. Mrs. L., aged 51, occupied for seven years a tenement, of which the papers, most of them quite old-fashioned, contained the following amounts of arsenic.

	Mgr. per Sq. Meter.	Grains per Sq. Yard.
Bedroom.	4.5	0.06
Room next bedroom, where patient occasionally sat.	611.7	7.83
Front and back parlor.	87.2	1.12
Kitchen.	51.0	0.65
Hall.	7.8	0.10
Dining-room.	23.1	0.30

For several months Mrs. L. had suffered with severe neuralgic pains, "accompanied, from time to time, by a good deal of constitutional disturbance." There was much gastric disturbance, with frequent attacks of nausea and vomiting. On removal to another house she began to improve and was getting much better, until, contrary to the physician's advice, she occupied a room of which the paper was arsenical (not sent to me for analysis). A return of the symptoms followed. When she finally took a room in which the papers were examined and found free from arsenic, she began to get better again, and since then had not shown any signs of a relapse. The urine, taken 60 days after removal from the first house, contained 0.01 mgr. per litre.

In the following cases the wall papers were not submitted to me for analysis:

Case 15. (Drs. Putnam and Driver, Case 14.) "The patient, being a lady of 58, showed, besides the more common symptoms of impaired nutrition and digestion, numbness of the hands at times and weakness in walking. In the presence of these symptoms, it is fair to suspect that a searching physical examination of the muscles, and of the sensibility of the skin might have justified a diagnosis of neuritis. Without that, the numbness of the hands at least can only be counted as a corroborative symptom. The source of the arsenic was not traced, but the patient improved on leaving home and relapsed on her return." 370 c. c. urine were analyzed July 14, 1886, and the amount of arsenic found was 0.005 mgr. per litre.

Case 16. (Drs. Putnam and Driver, Case 15.) "The patient suffered from 'epileptic vertigo,' which was not, however, attributed to the arsenic. She had also obscure digestive and nervous symptoms. The suspected paper was not removed, and the patient did not recover." 750 c. c. urine, July 1, 1886, gave 0.005 mgr. to the litre.

Case 17. (Drs. Putnam and Driver, Case 16.) "A variety of serious symptoms were present, referable to the nervous system and general nutrition, but Bright's disease was present, and for this reason it would not have been thought worth while to report the case, but that it is a question to be investigated whether arsenic may not occasionally set up a chronic nephritis. The source of the arsenic was not discovered." 1,080 c. c. urine, July 1, 1886, gave 0.055 mgr. per litre.

Case 18. (Drs. Putnam and Driver, Case 17). "Was that of a school teacher, thirty-six years old, and in a rather nervous and debilitated state through her work, without, at first, any distinctly characteristic signs of arsenical poisoning. During the summer months immediately following this period, she spent most of her time out of doors, and also changed her room, and seemed on the high road to recovery. In October, she returned to her former room, and immediately her old symptoms came back, and she was obliged to keep her bed, suffering from ringing in the ears, sleeplessness, attacks of colic at night, followed by diarrhœa, bad taste in the mouth, flatulent dyspepsia, irritation of the eyes and throat, and numbness of the hands. On account of the character of the symptoms, and because they became worse after the house was closed for a time and the furnace lighted, arsenic was suspected and sought for. The paper in the room was found to contain only a trace, but a frieze 20 inches wide and extending through three stories, gave 15 grains per square yard, and it was observed that the hallway formed a sort of shaft through which the heated air was conducted to the patient's bedroom, which was protected only by a portière, with an open space at the top. Furthermore, a small trunk room, the door of which opened next to hers, and which was used, with its window open, to ventilate her room, had an old paper with border and figure of Paris green. . . . The paper has been removed and the patient's gastric symptoms and sleeplessness are much relieved, though she is still under treatment." July 25, 1886, 760 c.c. of the urine contained 0.018 mgr. arsenious oxide per litre.

Case 19. (Drs. Putnam and Driver, Case 12). "Was interesting from the fact that here also were periodic attacks of gastralgia, occurring this time at night, but in addition occasional outbreaks of colic and diarrhœa. Insomnia and debility were also present. There were no other especially characteristic symptoms." May 26, 1886, 960 c c. urine gave 0.01 mgr. per litre.

Case 20. This case was also reported to me by Dr. Clarke. Mrs. D., aged 66, had lived in her tenement for nine years. During this time the rooms were papered in different years with papers which, in eight cases, were arsenical (not sent to me for analysis). "General weakness and nervous prostration have been pronounced symptoms of her case. The mouth and throat have been sore. The parts smart and sting, and the sensations extend into the trachea and œsophagus. The tongue is red, especially at the tip, the follicles are large, red, and protrude, and are very sensitive." On leaving the house for a short time, relief was immediate, but the symptoms reappeared on return to the house. July 2, 1886, the urine contained 0.005 mgr. per litre.

Discussion.

In all these cases the amount of arsenic eliminated by the kidneys is extraordinarily small, varying from 0.002 mgr. to 0.068 mgr. per litre. In the cases quoted in the historical sketch, the amounts could not have been much in excess of this, and in the analyses of Worcester given in Putnam's paper below, the quantity varied from 0.005 to 0.1 mgr. per litre.

I have been able to find but one quantitative determination of the rate at which small amounts of arsenic are eliminated. Hubbard,* in 1882, gives the following experiments. $\frac{3}{50}$ grain (3.87 mgr.) of arsenious oxide was given to a man, in pill form, for five days, and the urine of the last three days collected. On the third day no arsenic was found, on the fourth, 0.01 grain (0.65 mgr.), and on the fifth, "traces." Continuing, $\frac{6}{50}$ grain (7.74 mgr.) was given for two days, then $\frac{4}{50}$ grain (5.16 mgr.) for two days. On the eighth day, $\frac{1}{58}$ grain (1.12 mgr.), and on the ninth, $\frac{1}{83}$ grain (0.78 mgr.), was recovered. During this time the man was indoors and took no exercise. In the second case $\frac{5}{50}$ grain (6.45 mgr.) was given for six days to a man who took sufficient exercise each day to induce fatigue. On the fifth day $\frac{1}{110}$ grain (0.59 mgr.), and on the sixth day $\frac{1}{187}$ grain (0.35 mgr.), was recovered, the urine of the first four days not being examined. In the third case, the person was in feeble health and suffered from indigestion due to gastric catarrh. $\frac{3}{60}$ grain (3.24 mgr.) was given for six days, and on the sixth day no arsenic could be found. Then $\frac{6}{60}$ grain (6.48 mgr.) was given for six days more, and on the twelfth day $\frac{1}{125}$ grain (0.52 mgr.) was recovered. No attempt was made in any of the trials to follow the elimination until it stopped.

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* Physician and Surgeon, Ann Arbor, IV. 348; also, Contrib. Chem. Lab. Univ. Mich., I., Part 1.

When we consider that the determination of the arsenic was made by weighing the mirror obtained, and that the amounts varied from 0.35 mgr. to 1.12 mgr., the chances for error in weighing will be seen to be very great. Furthermore, the evaporated urine was added directly to the reduction flask, and Hubbard himself thinks that the organic matter is apt to interfere with the reduction and accurate deposition of the arsenic.

This, besides being the only quantitative series of experiments that I can find, concerns only the elimination when the arsenic is taken as arsenious oxide.

As to the rate of elimination, then, in cases of chronic wall paper poisoning, there are, so far as I know, no other data than in my experiments or in those of the historical sketch. Wood* has, however, recently made an investigation into the length of time required for elimination in cases where the poisoning occurred from other causes. His results are not quantitative. Two of the cases were chronic (from Fowler's solution), the third being acute (from arsenious oxide). In the first two, 58 and 82 days were required, and in the third 93 days. Wood also refers to a chronic case by Gaillard † (Fowler's solution), in which 53 days were required. In the cases given above, though the elimination was not examined to completion, the time after which arsenic still appeared varied from 19 days to 140 days.

But neither Wood's nor Hubbard's work enables us to draw an inference as to the rate of elimination from such minute doses as would come from a wall paper, and we have no parallel work whatever on the amount or rate when the arsenic is in the form of a derivative of arsenic acid.

In discussing the source of chronic wall paper poisoning, we have to consider in what state the arsenic compounds exist in the air of the room. The possibilities are two: a gaseous or volatile compound, and the solid particles mechanically detached from the paper. In addition to the action of the arsenical dust in the air, we are now in a position to consider the action of a volatile arsenical compound. The formation of a volatile compound from decaying arsenical matter, first discovered by Hamberg,* is now assured beyond question by the results of Gosio,† which I have confirmed, as shown in the foregoing paper. We have, then, either or both of these sources from which the arsenic can enter the system. Let us now consider the first of these.

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* Bost. Med. Surg. Journ., CXXVIII. 414.

† Ann. d'Hygiène, October, 1874.

As the amount of arsenic eliminated is so small, the amount ingested must be also small. As far as I can discover, no experiments have been made to investigate the action of *minute* quantities of arsenic when taken into the stomach, nor do I know of any work on the effect of inhaling air charged with minute particles of an arsenic compound. Furthermore, I have found no information on the action of minute quantities absorbed through the skin and mucous membranes. Thus we have no data to guide us to any conclusion as to the effect of *minute* quantities, however ingested. Yet, as in the case of larger quantities, the toxic effect is better known when taken into the stomach, we may use this channel as a basis of comparison while considering the reason for the action of minute quantities.

But little thought has been given to the compound, or to the state of oxidation in which the arsenic exists in the paper. We may divide the compounds into the trioxide and its derivatives, the pentoxide and derivatives, and the sulphides. Of the former the basic arsenite (Scheele's green) and the aceto-arsenite of copper (Schweinfurth, Paris, Mitis green) were formerly very common, but are now rare in wall paper, though they may appear in domestic fabrics. We may have also the trioxide itself, and possibly a few other arsenites. The sulphides may occur occasionally. But in a very large number of the papers of to-day which contain arsenic the higher oxidation state is found. The use of arsenic acid in the manufacture of rosaniline is liable to leave arsenic in the color as an arseniate, as well as arsenite, while the use of the arseniates as mordants is very common, especially in fabrics.

The effect of arsenious oxide and its derivatives may be inferred to a certain extent from the well known action of larger amounts, but in the case of the action of minute amounts of the sulphides and arseniates we have little to guide us. I have found a few cases of poisoning from arseniates, but, with one exception, a case of poisoning by potassic arseniate,* the chemical tests show the substance to have been an arsenite.

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* Pharm. Journ. and Transactions, [3], V. 81; Pharm. Zeitschr. f. Russland, XXV. 779.

† Azione di Alcune Muffe sui Composti Fissi d'Arsenico, Roma, 1892.

The difference in action between arsenious and arsenic acids was first studied by Wöhler and Frerichs † in 1848, arsenic acid previous to that time having been considered more poisonous than arsenious acid. They concluded that the arsenic acid was less active than the arsenious, following the analogy of the phosphoric and phosphorous acids. They thought that the arsenic acid was reduced in the organism to arsenious acid. They also proved the poisonous quality of calcic arseniate, although it is insoluble. This is also shown by Schmidt and Bretschneider.‡ Schroff,§ in 1852, experimented more carefully than Wöhler and Frerichs, and came to the conclusion that arsenic acid was not very much less poisonous than arsenious acid. Marmé,‖ in 1875, quotes Savitsch,¶ who found that the poisonous qualities stood in the same ratio as the percentage of metallic arsenic in each. Marmé, however, in a carefully conducted series of experiments, was able to show that arsenic acid is much the less energetic. Reichardt** remarks the necessity of determining the state of the arsenic, in order to know whether it is injurious or not. He considers that arsenic acid may be combined with iron in ochres, and supposes ferric arseniate to be harmless. Yet if calcic arseniate is poisonous, why not ferric?

If arseniates are less poisonous in large doses, is it because they are less of an irritant? If less irritating, could they be accumulated more easily if in minute doses?

This leads to the consideration of the localization of arsenic in chronic cases. Scolusuboff,†† in 1875, found the deposition, when taken as arsenious oxide and sodic arsenite, to be chiefly in the brain, "from which it is carried by the circulation to other organs." Ludwig,‡‡ in 1881, finds this assertion to be wrong as far as arsenious oxide is concerned, the brain containing comparatively little, while the liver contained the most and held it longest. This view is confirmed by Guareschi,* Bergeron, Delens, and L'Hote,† and Johnson and Chittenden.‡ Chittenden § gives an exhaustive analysis of a body, with quantitative results as far as he could go by his method. The largest amount of arsenic was in a muscle from the back, next in the intestines, and next in the liver. The kidneys contained very little, the brain somewhat more than the kidneys. Chittenden was of the opinion that a marked difference was made in the distribution according to whether the arsenic was given in one dose or in several.

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* Bouley, jeune, Mém. Acad. Roy. de Méd., Paris, 1835, IV. 298-307.

† Ann. d. Chem. u. Pharm., LXV. 345.

‡ Moleschott's Untersuchungen, 1859, VI. 146.

§ Archiv f. phys. u. path. Chem. u. Mikr., Wien, V. 241.

‖ Nachr. v. d. könig. Gesells. d. Wissens. a. d. Georg. Aug. Univ., Göttingen, 1875, p. 614.

¶ Dissertation, Dorpat, 1854.

** *Loc. cit.*

†† Archiv de Phys. norm. et path., 1875; also, Ann. d'Hygiène publ. et de Méd. légale, Jan., 1876.

‡‡ Jour. de Pharm. et de Chemie, [5], VI. 198; also, Chem. Centralblatt, 1881, p. 90.

All this work, however, with the exception of Scolusuboff's, has to do with arsenious oxide alone. There is no evidence to show that the same rate or place of distribution holds good for other compounds of arsenic, especially for the arseniates, and we also have no means of knowing where the arsenic goes when ingested in minute, continued doses.

Schmidt and Bretschneider ‖ investigated the question whether the urine contained arsenious or arsenic acid when the arsenic was taken as the trioxide. Their method was somewhat unsatisfactory. Arsenic acid was found and no arsenious, but possibly with a better method they would have found arsenious acid also. Yet the arsenic acid was undoubtedly in excess. Would a minute quantity of an arseniate pass eventually into the urine with less acute disturbance? In the same investigation the above authors examined the effect of metallic arsenic when taken in a perfectly pure state, and found it to cause no acute poisoning. Metallic arsenic was found in fæces and urine. This work was a repetition of that of Schroff,¶ who, using impure material had found metallic arsenic to be poisonous.

A statement of the facts we now possess in regard to the volatile compound is in order here. A brief *résumé* of Gosio's work on this subject has been recently given by Shattuck.**

The compound is generated by the action on arsenical organic matter of the following moulds: *Penicillium brevicaule*, *Mucor mucedo*, *Aspergillum virens*, and *Aspergillum glaucum*, a few others having been found which have a slight action. Of these the most intense action is caused by the first, a mould discovered on decaying paper, though *Mucor mucedo*, which is more widespread than the first, is only a little less active. The conditions for development of the compound by these moulds are moisture, a temperature from 15 to 35° C. (60–95° F.) and a supply of oxygen, without which no action takes place. A large amount of arsenic retards the growth, which goes on best in a ground containing 0.01 to 0.05%. The best nutritive material is a carbohydrate. The development may take place in presence of arsenious oxide or its derivatives, or of arseniates, though the latter seem to me to have given the best results. Little or no action is obtained from the sulphides.

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* Gazzeta Chim. Italiana, XIII. 176.

† Ann. d'Hygiène publ. et de Méd. légale, [3], III. 23.

‡ Amer. Chem. Journal, II. 232.

§ Ibid., V. 8.

‖ *Loc. cit.*

¶ Zeitschr. der Wiener Aerzten, 1858, I. 4.

** Bost. Med. Surg. Journ., CXXVIII. 540.

As to the nature of the volatile compound it was thought from the work of Hamberg and the speculations of others to be arseniuretted hydrogen, an assumption that has been very misleading. Certainly very little, and I think none, is formed. As far as the results go, the compound seems to be a neutral organic derivative, and my opinion is that the results favor its being an organic derivative of arsenic pentoxide. No definite properties beyond its peculiar alliaceous odor and volatility have been found, except that the yellow compound noticed by Hamberg, Gosio, and myself may be a "molecular" compound with argentic nitrate.

It may be remarked in passing that the proof of the formation of a volatile compound is a complete explanation of the poisoning in many cases where an arsenical paper underlies one that is free from arsenic. Also, though the effect of an arsenical paper may be temporarily lessened by a varnish or size, that the danger is not removed.

With the volatile compound we have to consider the question not only of more minute doses than in the case of dust, but of a form which permits the arsenic to enter the system more easily by the lungs and in a state differing greatly from any dust. Whether we have a derivative of arsenious or arsenic acid, the fact that the molecule contains carbon is a very important one.

The experiments of Schröter* on the poisonous action of p-benzarsenic acid, $C_6H_4(CO_2H) . AsO(OH)_2$, are interesting here, though it is not likely that the volatile compound is an aromatic derivative. Schröter found that the amount of arsenic in a fatal dose of benzarsenic acid was somewhat larger than in a fatal dose of either arsenic or arsenious acids, but that death followed after a much longer interval than with either of the others. The early symptoms were referable to benzoic acid, the later to arsenical poisoning.

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* Inaug. Dissert., Erlangen, 1881.

In chronic poisoning a tolerance was established to such an extent that five times as much could be given as would be fatal to an animal not accustomed. In the urine immediately after ingestion an arsenical organic acid other than benzarsenic acid was found, but could not be detected afterward, though the urine was arsenical.

Schröter ascribes the difference in action between benzarsenic and the two inorganic acids to the carbon in the molecule, a separation into benzoic acid and arsenic acid having to be made before the latter can act.

Selmi* claims to have isolated from decaying arsenical animal matter an arsenical alkaloid and a ptomaine, and Husemann,† on the strength of this, thinks that an arsenical ptomaine may be formed by the decomposition of arsenical paste by mould. There is no evidence, however, to show that the volatile compound is of the nature of a ptomaine.

An important contribution to the knowledge of chronic wall paper poisoning was made about three years ago by Putnam,‡ who collected a number of samples of urine mainly from hospital patients, selecting chiefly those cases in which there were no symptoms referable to arsenical poisoning. These samples, 48 in number, were analyzed by Dr. C. P. Worcester, and traces of arsenic found in 21 (44%). A year later,§ Putnam added to this list, making the total number of samples 150, of which Worcester found over 30% arsenical. The method of analysis used was similar to that described in this paper. These results prove the wide distribution of arsenic in articles of household use, and show also that the system is evidently capable, in many cases, of absorbing and eliminating minute quantities of arsenic where a large quantity would act as an irritant.

The following facts may now be noted: —

1. The distribution of arsenic in articles of domestic use is very wide, and it has been shown that it finds its way into the system in many cases where there is no poisonous effect.

2. It is now pretty conclusively shown that arsenic may be in some cases accumulated, instead of always being readily eliminated.

3. The amount of arsenic absorbed in chronic wall paper poisoning may be very minute, but it is in continued doses.

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* Mem. d. Accad. d. Scienze, Bologna, [4], I. 299.

† Arch. d. Pharm., CCXIX. 415.

‡ Bost. Med. Surg. Journ., CXXII. 421.

§ Ibid., CXXIV. 623.

4. The elimination of the arsenic by the kidneys in wall paper poisoning is very slow and the amount eliminated very small.

5. The absorption of the volatile compound, though in smaller amounts, is more direct than that of the dust particles, and the action is modified by the presence of carbon in the compound.

6. The effect of minute doses of any compound of arsenic, in whatever way ingested, has not been studied.

7. The effect of any quantity whatever of many compounds of arsenic that occur in wall papers and fabrics, notably arseniates, is not well known, whether the arsenic compound be taken at once or in continued doses.

8. The localization of any compound of arsenic and particularly of the arseniates, when taken in minute continued doses, has not been studied.

9. The salts of arsenic acid seem to be less irritating than those of arsenious acid. Is this because the state of oxidation permits its readier accumulation?

My position does not permit me to advance any decided opinion on the source of chronic wall paper poisoning, and I can only submit the above facts for consideration. From the facts, however, that have come to my notice during the preparation of these two papers, I cannot help making the following suggestion: —

Chronic arsenical poisoning from wall papers and fabrics may be chiefly due to the ingestion of minute continued doses of arsenic as a derivative of arsenic pentoxide, which from its state of oxidation is likely to be accumulated in the system, from which it is slowly eliminated. The absorption may be from an inorganic arseniate in the form of dust, or from a volatile organic derivative of arsenic acid, or from both.

The remark of Dragendorff,* that a part of the arsenic acid may go into the bones in place of phosphoric acid, should be remembered here. It seems quite possible that calcic arseniate, being isomorphous with calcic phosphate, should replace a part of the latter. This may be confirmed by Ludwig† and Gibb,‡ both of whom found arsenic in the bones, Ludwig finding that it was held there long after the doses ceased. Evidently a large field of investigation must be cleared before a definite conclusion can be reached as to the cause of chronic wall paper poisoning.

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* Ermittelung v. Giften, 1876, p. 326.

† *Loc. cit.*

‡ Trans. Pathol. Soc. London, 1858, IX. 442.

In conclusion, it must be remarked that both Gosio's and my work have shown that a very small amount of arsenic may be quite as good a source of the volatile compound as a very large amount. Hence the limit that can be set as a dangerous amount of arsenic in a wall paper is a matter which should be very carefully considered. It has been thought by many that a paper containing under 0.1 gr. per square yard (8 mgr. per sq. m.) was harmless. If the arsenic were given off as dust alone, perhaps this limit would be sufficient, but, with the chance for the formation of the volatile compound, we cannot, I think, say that 0.1 gr. per square yard is harmless. The matter of limit emphasizes the need of a quantitative analysis of the paper. By the process I have described and referred to here, this is a simple matter, and every paper should be reported, not in the indefinite "traces," "large amounts," "dangerous quantity," etc., but with the approximate figures, so that the physician may *himself* decide as to whether the paper should be rejected or not.

Washington University Chemical Laboratory,
Saint Louis, September, 1893.

VI.

ON THE AUTOMORPHIC LINEAR TRANSFORMATION OF A BILINEAR FORM.

By Henry Taber.

Presented January 10, 1894.

In the *Philosophical Transactions* for 1858, Cayley gave the following determination of the general automorphic linear transformation of the alternate bilinear form with cogrediant variables

$$(\,\Omega\,\overset{\wedge}{)(}\,x_1, x_2, \,.\;.\;.\;\overset{\wedge}{)(}\,y_1, y_2, \,.\;.\;.\;),$$

namely,

$$(\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon),$$

in which Υ denotes an arbitrary symmetric linear transformation.

As shown by Cayley, this is equivalent to the determination of the general solution of the matrical equation $\breve{\phi}\,\Omega\,\phi = \Omega$, in which Ω is a known skew symmetric matrix, and $\breve{\phi}$ denotes the transverse of ϕ. Cayley's solution of this equation fails for those matrices ϕ of which -1 is a latent root.

If Ω is real, and is both skew symmetric and orthogonal (i. e. if $\Omega^{-1} = \breve{\Omega} = -\Omega$), the product of two of Cayley's expressions gives every real solution of this equation.

Thus, let ϕ be any real solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$, of which -1 is a latent root. A polynomial $\Phi = f(\phi)$ in integer powers of ϕ with real coefficients can be formed, containing every factor in the identical equation to ϕ, except $\phi + 1$, and such that

$$\Phi^2 = \Phi, \ \breve{\Phi}\,\Omega = \Omega\,\Phi.^*$$

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* The latent roots of ϕ being ± 1 of multiplicity m and n respectively, g_r, g_r^{-1}, each of multiplicity p_r, for $r = 1, 2, \ldots i$, the identical equation to ϕ is

$$(\phi - 1)^m\,(\phi + 1)^n\,(\phi - g_1)^{p_1}\,(\phi - g_1{}^{-1})^{p_1}\,(\phi - g_2)^{p_2}\,(\phi - g_2{}^{-1})^{p_2} \ldots = 0\,;$$

and if

$$F_r(z) = [(z+1)^n - (g_r^{+1})^n]^{p_r}\,[(z+1)^n - (g_r^{-1}+1)^n]^{p_r},$$

If now

$$\bar{\phi} = \phi\,(1 - 2\,\Phi)\,;$$

then -1 is not a latent root of $\bar{\phi}$, and $\bar{\phi}$ is a solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$. The matrix $\phi_0 = (1 - 2\,\Phi)$ is also a solution of this equation; and we have $\phi_0^2 = 1$. Therefore

$$\breve{\phi}_0\,\Omega = \Omega\,\phi_0 .$$

But if

$$\Omega\,\phi_0 = \psi$$

we then have

$$\breve{\psi} = -\psi .$$

Since $\phi_0 = \Omega^{-1}\,\psi$, and since $\phi_0^2 = 1$, we have

$$\Omega^{-1}\,\psi\,\Omega^{-1}\,\psi = 1 .$$

Therefore,

$$\begin{aligned} \breve{\psi}\,\Omega\,\psi &= -\psi\,\Omega\,\psi \\ &= \psi\,\Omega^{-1}\,\psi \\ &= \Omega\,. \end{aligned}$$

Consequently ψ is also a solution of the equation.

The matrix $\bar{\phi}$ has no latent root equal to -1. The matrix Φ, and therefore ϕ_0, are real; ψ is then a real skew symmetric matrix, and consequently has no latent root equal to -1. Therefore both $\bar{\phi}$ and ψ may be represented by Cayley's expression. Therefore the most general real solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$, in which Ω is a real skew symmetric matrix such that $\Omega^2 = -1$, is

$$\phi = \Omega^{-1}\,(\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon)\,(\Omega - \Upsilon')^{-1}\,(\Omega + \Upsilon'),$$

in which Υ and Υ' are arbitrary real symmetric matrices. The expression

$$(\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon)\,(\Omega - \Upsilon')^{-1}\,(\Omega + \Upsilon')$$

is equally general.

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$$\Phi = \frac{[(\phi + 1)^n - (1 + 1)^n]^m}{(-1)^m\,(2)^{mn}}\;\frac{F_1\,(\phi)}{F_1\,(-1)}\;\frac{F_2\,(\phi)}{F_2\,(-1)}\;\cdot\cdot\;\frac{F_i\,(\phi)}{F_i\,(-1)}\,.$$

Since ϕ is real, its imaginary latent roots occur in pairs which are conjugate imaginary, and have the same multiplicity. From which it follows that Φ is real.

VII.

CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF
THE MUSEUM OF COMPARATIVE ZOÖLOGY, UNDER
THE DIRECTION OF E. L. MARK, XXXIX.

ON SOME LAWS OF CLEAVAGE IN LIMAX.

A PRELIMINARY NOTICE.

BY C. A. KOFOID.

Communicated by E. L. Mark, January 10, 1894.

THE following is a statement of the results obtained from the study of cleavage in Limax, and of the literature of cell lineage in other invertebrates. It is desirable to confirm my results by a study of cleavage in other forms before the publication of my final paper, and it has therefore seemed best not to defer the presentation of the conclusions to which I have arrived.

A few words in regard to the usage of terms will be necessary. The egg is regarded as having the animal pole uppermost, and the terms *right* and *left*, *upper* and *lower*, are used as resident in the egg itself. Or, to express it in another way, a miniature observer is imagined as placed in the principal (vertical) axis of the egg, with his head at the animal pole, facing the part or parts of the egg under discussion, and the terms *right* and *left*, *upper* and *lower*, are used as determined by this observer. By "a generation of cells" is meant all those cells which are removed from the ovum by the same number of cell divisions, regardless of the time of appearance or position of such cells, i. e. the word is used in its literal sense. This is not the usage of Fol ('75) or Blochmann ('81), who employ the term in its literal sense with reference to the blastomeres through the four-cell stage, but thereafter use it to designate successive sets of four micromeres, naming them in the order of their appearance in time.

As is well known, cells cleave in sets of fours throughout the spiral period of cleavage. The cleavage of the individual cells of the set may be synchronous or successive, and the cleavage of any given set may or may not coincide with that of the other sets of the same generation; but whatever the modifications, each cell in its origin bears a close relation to three other cells, and these sets of four related cells of co-ordinate origin will be called *quartets*. During spiral cleavage the egg is made up of a number of superposed quartets, and it may be compared to a house of as many stories, each story representing a single quartet of four cells.

The regions of the cleaving egg occupied by the four blastomeres of the four-cell stage and their derivatives during the spiral period will be called *quadrants*, and the four primitive blastomeres and their respective derivatives will be designated by the letters *a*, *b*, *c*, *d*, taken in the order in which the hands of a clock move. In Nereis and Umbrella, these designate the left anterior, right anterior, right posterior, and left posterior quadrants respectively.

The term *spiral* will be used to indicate the divergence immediately after cleavage of the centre of the nucleus of the UPPER one of two daughter cells from the vertical plane passing through the corresponding portion of the LOWER cell and the vertical axis of the egg. The spiral will be a right spiral when the divergence is toward the right (as defined above), and a left one when the divergence is toward the left. Or, using Blochmann's ('81) comparison to the hands of a clock, when the egg is observed from the animal pole the spiral is a "right" one if the divergence of the upper cell is in the direction of the motion of the hands of the clock, a "left" spiral if the divergence is opposite the motion of the hands of the clock. By this method of nomenclature all those spirals whose spindles stand in similar positions with reference to the vertical axis are given the same name.

It should be noted in this connection, that this divergence, or apparent shifting of cells, in Limax at least, is the result of the obliquity of the plane of division, and is predetermined by the *position of the spindle*. This fact, whatever may be the cause of the particular position of the spindle, is the immediate basis of the phenomenon termed the "spiral." The position of the spindle primarily determines the position of the daughter cells, though mechanical environment may secondarily modify that position.

The nomenclature of spirals as followed by Blochmann ('81), Lang ('84), Wilson ('92), Heymons ('93), and others, presents no constant basis of reference. Not only have these authors named homologous spirals differently, as Lang ('84, p. 325) and Heymons ('93, p. 256), but no one of those named except possibly Lang has used the same method of naming *all* the spirals discussed. In some cases the lower cell of a pair of daughter cells is regarded as the fixed one, in other cases the upper cell is so regarded; or, to express it differently, in some cases peripheral cells are regarded as fixed, in other cases axial ones. In general it seems to have been the custom to consider the larger of the daughter cells as fixed, and the budding smaller cell as the movable one. Two reasons may be cited for the employment of the relative size of the daughter cells as a basis for the nomenclature of the spiral. (1) The larger cell occupies more nearly the position of the mother cell, and it is therefore natural to regard the smaller cell as the movable one. (2) In the first spiral the larger cells (macromeres) are *basal*, and the micromeres upon them are therefore regarded as the movable cells, and this basis adopted in the first spiral is suggested for other spirals. Though this reference of the spiral to the relative size of the cell may furnish a logical basis for nomenclature of spirals where cleavage is *unequal*, it cannot furnish one for those spirals, or eggs, in which cleavage is *equal*. Nor has this basis when once adopted been consistently followed in every case, — as, for example, in Wilson's paper on Nereis ('92). On page 391 he says: "A careful study of the embryo through these changes shows that all of the cell divisions conform to the spiral type. . . . It is also easily seen in the divisions of the secondary micromeres (a^2, b^2, c^2, X). Each of them divides somewhat obliquely (cf. Figs. 25, 26, 33) so that one of the cells lies somewhat lower than the other, and in most cases the lower cell is obviously smaller than the upper. The difference in size is very great in the case of X and x', but is much less in the case of the others ($a^{2.1}$, $a^{2.2}$, Fig. 33). (In the specimen shown in Figs. 25, 26, on the other hand, there is no appreciable difference in size, but I have never seen a case in which the upper cell is the smaller.) If this group of cells be followed around the embryo from right to left (against the hands of a watch), the upper (larger) cell always comes first; i. e. the first division of the second group of micromeres takes place in a left-handed spiral, *like the second division of the first set of micromeres*."

There is no escape from the conclusion that in this case the cell of reference is the *larger* one, as it was in the case of the "third and fourth cleavages" (cf. Wilson, pp. 387 and 388). That it is the "larger" rather than the "upper" cell, will be seen when in Wilson's Fig. 21 (reproduced in outline in my Plate I. Fig. 5) we apply to the spirals foreshadowed in the spindles of the cells d^1, X (= d^2), and D, the method employed by him in naming this spiral (a^2, b^2, c^2, X). Following around the embryo from right to left the "upper" cell (indicated by the upper end of the spindle) comes first in all three cases, but the spirals are *not all given the same name.* The "larger" cell comes first in d^1 and X, and the spirals are called left-handed spirals. The smaller cell comes first in D, and the spiral is called a right-handed spiral (p. 391). — Let me call attention, in passing, to the fact that, in the system of nomenclature I have proposed, the three spirals above referred to would be given the same name. They would *all* be called right spirals, and in this similarity of name would be recognized the similarity of the position of spindles, and the fact that in passing from right to left the *upper cell* always comes first. The basis on which my system rests is not the varying *size* of the cells, but the more fundamental factor of *position.*—Up to this point in cleavage Wilson has consistently used his system of nomenclature, but upon the next page (p. 392), in discussing the third division of the primary micromeres a^1, b^1, c^1, d^1, resulting in the formation of the cells a^1, b^1, c^1, d^1, and the rosette cells $a^{1.3}$, $b^{1.3}$, $c^{1.3}$, $d^{1.3}$, he abandons the larger cell as the basis of reference, as will be seen in the following quotation: "The four primary micromeres (a^1, b^1, c^1, d^1) bud forth four small cells at their inner angles (at the upper pole) which arrange themselves in a very regular apical rosette, the cells of which alternate with the central micromeres (Figs. 27, 28, etc.). The position of the spindles is the same as in the first division of a^1, b^1, c^1, d^1; i. e. the division follows a right-handed spiral, but the character of the division is very different since the smaller cells are formed at the central instead of the peripheral angles of the cells (i. e. towards instead of away from the vertical axis of the embryo)." In this case the fact that "the position of the spindles is the same" is cited as a basis on which the spiral is named. In my Fig. 6, Plate I., is reproduced in outline Fig. 25, Plate XV., of Wilson's paper. If we apply to the cells c^1 and $c^{1.3}$ the test mentioned by Wilson on page 391, and name the spiral according to the size of the cell that "comes first," we must call it, not a right-hand, but a left-hand spiral. This is the only case in which the similarity of the position of the spindles is recognized as a factor in the nomenclature of spirals. By this change in the basis of nomenclature he has recognized the interesting fact that there exists in the three successive divisions of the primary micromeres (a^1, b^1, c^1, d^1) an alternation in the direction of the spirals.

This alternation, as described and named by him, is *independent* of that which exists in the first three divisions of the macromeres. It belongs to an entirely separate system, and its relation to successive generations of cells is neither suggested nor discussed.

Not only does the system of nomenclature based on the size of the cells fail to furnish a logical basis for cases of equal cleavage, but it also fails to furnish such a basis for the comparison of cleavage in different forms, for the cells in which the yolk is lodged in the progress of cleavage are by no means homologous cells in different species (cf. Nereis, Neritina, and Umbrella). It therefore seems to me very much more logical to base the nomenclature of spirals upon constant spatial relations than upon the relative sizes of the daughter cells, which are inconstant, or upon the apparent greater shifting of one of the daughter cells referred to *no constant plane.*

The student of cell lineage finds his task much complicated by the various systems of nomenclature already employed, and it seems a pity to introduce still another to add to the confusion. But as all systems heretofore employed fail to recognize the fundamental importance of sucessive *generations of cells,* and as these are the basis of my treatment of the subject, it has been impossible to adopt any of the existing systems. At the same time, it is believed that the system proposed, resting as it does upon generations of cells, is adapted to all forms of spiral and radial cleavage, and will furnish a satisfactory and convenient means of comparison in these cases. Its applicability to spiral cleavage will now be discussed more fully.

Each individual cell of an egg in spiral cleavage can be traced back to one of the four blastomeres *a, b, c, d,* i. e. it belongs to a definite quadrant. It also belongs to a definite quartet or "story" of the egg; it is likewise removed from the ovum by a definite number of cell divisions, i. e. belongs to a definite generation.

Any system of nomenclature involving these three factors will both localize the cell and outline its ancestry. *Each cell of the* *spiral period of cleavage may therefore be designated by three characters:* (1) *a letter, as a, b, c, d, indicating the quadrant;* (2) *a first exponent indicating the generation, as* $a^{4\cdot}$, $a^{5\cdot}$, *etc.;* (3) *a second exponent indicating the quartet or story, as* $a^{4.1}$, $a^{4.2}$, $a^{7.16}$, *etc.* Generations are numbered starting with the ovum as the first generation. The number of cells doubles with each succeeding generation, and after the third generation, i. e. after the four-cell stage or the first quartet, the number of quartets is also doubled. The quartets or stories are numbered *from the vegetative toward the animal pole.* Thus in the eight-cell stage the lower quartet is designated by the exponent 1, and the upper quartet by the exponent 2. This principle is followed in the nomenclature of all quartets. During the period of spiral cleavage, the two daughter cells (or quartets) resulting from the cleavage of any given cell (or quartet) never lie in the same plane, and the *lower* cell (or quartet) of the two is always designated by an *odd* exponent and the upper by an *even* one. Thus, when $a^{5.3}$ (— $d^{5.3}$) divides, the resulting cells (quartets) are $a^{6.5}$ (— $d^{6.5}$) and $a^{6.6}$ (— $d^{6.6}$), the latter being nearer the animal pole. The second exponent of the upper daughter cell is always twice the corresponding exponent of the mother cell, and that of the lower cell twice less one. The quartets are thus designated as though all the quartets of their generation were *actually* present, a condition rarely realized in later generations; however, these quartets are potentially present, being represented by their ancestors or descendants, and no confusion need arise over this point.

The following is a scheme of the nomenclature through the sixth generation: —

First.	Second.	Third.	Fourth.	Fifth.	Sixth.
$\overline{abcd}^1$	$\overline{ab}^2$ $\overline{cd}^2$	a^3 b^3 c^3 d^3	$a^{4.2} — d^{4.2}$ $a^{4.1} — d^{4.1}$	$a^{5.4} — d^{5.4}$ $a^{5.3} — d^{5.3}$ $a^{5.2} — d^{5.2}$ $a^{5.1} — d^{5.1}$	$a^{6.8} — d^{6.8}$ $a^{6.7} — d^{6.7}$ $a^{6.6} — d^{6.6}$ $a^{6.5} — d^{6.5}$ $a^{6.4} — d^{6.4}$ $a^{6.3} — d^{6.3}$ $a^{6.2} — d^{6.2}$ $a^{6.1} — d^{6.1}$
1 cell.	2 cells.	4 cells.	8 cells.	16 cells.	32 cells.

The advantages of this system are as follows. (1) It does not involve the confusion of designating two or more different cells by the same characters, as is the case when a daughter cell is given the same designation that the mother cell had; e. g. when the macromere *A* divides, and the derivatives are named *A* and a^1 and the same designation is employed for the basal cell in the succeeding divisions. (2) Never more than two exponents need be employed, and practically the limit of three figures is not exceeded. We thus avoid the cumbersome and confusing exponents which characterize the late periods of cleavage in other systems; e. g. $a''_{1.2.1}$ of Heymons ('93, p. 259, Taf. XV. Fig. 20) becomes $a^{9.25}$. (3) The designation affords some clue to the relative position of the cell and the quartet to which it belongs. Thus the quartet with the second exponent 1 is always at the vegetative pole of the egg. The apical quartet is always designated by one of the even numbers 2, 4, 8, 16, 32, etc. The exponents of any cell give a hint as to the designation of the adjoining cells. Thus, $b^{6.8}$ of Figure 3 (Plate I.) lies in contact with $a^{5.3}$ and $b^{5.3}$ and $b^{6.7}$. (4) The derivation of a cell is implied in its designation in every case. Thus, $b^{6.8}$ is derived from the cell *b* of the fifth generation and fourth quartet, i. e. from $b^{5.4}$, $b^{5.4}$ from $b^{4.2}$, and $b^{4.2}$ from b^3. The mother cell of any given cell is always designated (1) by the same letter, (2) by the first exponent of the daughter cell less one, (3) by one half of the second exponent when that exponent is even, or by one half the sum of the second exponent and one when it is odd. Thus, $b^{6.7}$ and $b^{6.8}$ are derived from $b^{5.4}$. In like manner, the designation of the mother cell determines that of the daughter cells; for example, when $b^{4.2}$ divides, the daughter cells are always designated as $b^{5.3}$ and $b^{5.4}$, *whatever their position and relation to other cells or quartets.* In typical cleavage they will be members of the third and fourth quartets from the vegetative pole. This typical condition is, however, sometimes modified by delayed cleavage, or by the distribution of the yolk.

This system of nomenclature may also be extended to the cleavage of the bilateral period, and to the radial type of cleavage. In the case of cleavage in a plane parallel to the equator, the upper and lower daughter cells may be designated as in the spiral period and type of cleavage. In meridional cleavages the *right* derivative may be designated by the *even* exponent and the *left* by the *odd* in the case of *even* generations, and the reverse in the case of *odd* generations. Macromeres when present may be designated by capital letters, or any special quartet, as the "primary micromeres" may be distinguished by special forms of type without change of letter or exponents, or subordinate dichotomous systems may be introduced for protoblasts and their progeny.

My work upon Limax is as yet incomplete, but it is probable that at least through the thirty-six-cell stage the cleavage of Limax is identical, blastomere for blastomere, spiral for spiral, with that of Nereis. Beyond that stage I have not followed the cleavage. In the eggs of *Limax agrestis* the yolk is almost equally distributed, and cleavage is almost equal. Macromeres in the etymological sense do not exist after the eight-cell stage, and it is with difficulty that the poles of the egg can be distinguished by the size of the blastomeres after the sixteen-cell stage.

The discussion in Limax will be limited to the generations from the third to the sixth, inclusive.

Third Generation. The cells (a, b, c, d) of the four-cell stage present the typical arrangement of the furrows at the vegetative and animal poles, and the spiral, as indicated by the obliquity of the spindles, must be called according to my nomenclature a *left* spiral, as Heymons ('93, p. 249) has called the similar spiral in Umbrella.

The *Fourth Generation* is reached in the eight-cell stage by the formation of four macromeres ($a^{4.1}$, $b^{4.1}$, $c^{4.1}$, $d^{4.1}$), and four micromeres ($a^{4.2}$, $b^{4.2}$, $c^{4.2}$, $d^{4.2}$), Plate I. Fig. 1. Each micromere as a result of the obliquity of the spindle lies above and to the right of the macromere which has a cognate origin with it, and the spiral is therefore a *right* spiral.

Fifth Generation. The two quartets of the preceding generation divide at about the same time, giving rise to the sixteen-cell stage composed of the four quartets $a^{5.1}-d^{5.1}$, $a^{5.2}-d^{5.2}$, $a^{5.3}-d^{5.3}$, and $a^{5.4}-d^{5.4}$. An inspection of Plate I. Fig. 1, shows that the nuclear conditions of the first quartet are slightly in advance of those of the second quartet. Consequently in Limax the twelve-cell stage is abbreviated almost to obliteration, the egg passing from the eight- to the sixteen-cell stage without the intervention of a pronounced twelve-cell stage. This lateral view of the egg also shows that all of the spindles stand in a similar position with reference to the vertical axis, i. e. the direction of their obliquity is the same, so that if they should be spread out in a plane parallel with the vertical axis of the egg they would be approximately parallel to one another. The left aster is in every case the upper one; and at the end of division the upper derivative will lie to the left of the lower one, not to the right, as in the preceding and in the following generation. The division of the cells will take place in a plane approximately at right angles to that of the preceding division, and approximately parallel to the one preceding that. *This alternation of the direction of the spindles and planes of division in successive generations* is a phenomenon independent of any system of nomenclature of "spirals." It is a factor, however, which in my opinion should be given weight in any system of nomenclature. If we give to the spiral of the second quartet the designation hitherto universally applied to it, we must call it a *right* spiral, and thus ignore the factor of alternation, for that of the first quartet and same generation is called a left spiral. If, on the other hand, we recognize this similarity in the direction of the obliquity of the spindles of both quartets of this generation, we should give their spirals the same name. This is accomplished by referring the nomenclature of the spiral to the basis suggested in the preceding pages, i. e. by regarding the lower of the two daughter cells as fixed, the upper one as movable or diverging. In the case of the two dividing quartets under discussion the *upper* asters of both quartets are the *left* asters, and consequently of the daughter cells the *upper* is the left; i. e. the direction of the divergence or rotation is toward the left, or opposite the direction in which the hands of a watch move, and the spirals in BOTH quartets should be called LEFT spirals.

The *Sixth Generation* is produced by the division of the four quartets of the fifth generation, $a^{5.1}-d^{5.1}$, $a^{5.2}-d^{5.2}$, $a^{5.3}-d^{5.3}$, and $a^{5.4}-d^{5.4}$, which results in the formation of the eight quartets $a^{6.1}-d^{6.1}$, $a^{6.2}-d^{6.2}$, $a^{6.3}-d^{6.3}$, $a^{6.4}-d^{6.4}$, $a^{6.5}-d^{6.5}$, $a^{6.6}-d^{6.6}$, $a^{6.7}-d^{6.7}$, and $a^{6.8}-d^{6.8}$.

These divisions are not synchronous, however, neither are they all accomplished before the divisions resulting in the succeeding (seventh) generation begin; for from this time on in the history of the egg successive generations of cells overlap one another, so that we find in the egg at the same time cells belonging to two or more generations. In every case the cell is designated as though all the other cells of that quartet, and all other quartets of that generation, were actually present. Thus in Plate I. Fig. 3, the cell $c^{6.7}$ is the only one of its quartet actually formed, and only six of the eight quartets of the sixth generation have as yet arisen. The missing cells and quartets are of course represented in their ancestors of the fifth generation. The divisions of the quartets resulting in the sixth generation will be discussed in the order of their occurrence.

First Quartet. The cells $a^{5.1}$–$d^{5.1}$ divide, forming $a^{6.1}$–$d^{6.1}$ and $a^{6.2}$–$d^{6.2}$ (Plate I. Figs. 2, 4). The cells of the latter (second exponent = 2) lie above and to the right of those of the former (second exponent = 1) with which they are associated (Plate I. Fig. 2). Therefore the spiral is a *right* spiral. In this generation, as in the preceding, it will be observed that the basal quartet is the first to divide.

Second Quartet. The cells of the quartet $a^{5.2}$– $d^{5.2}$ divide, forming $a^{6.3}$– $d^{6.3}$ and $a^{6.4}$– $d^{6.4}$ (Plate I. Figs. 2, 3, 4), and, as in the preceding quartet, every cell with an even exponent lies above and to the right of the one which was cognate with it, and which has an odd exponent. Therefore this spiral is also a *right* spiral. This division follows immediately upon that of the preceding (first) quartet, and results in the twenty-four-cell stage of Figure 2 (Plate I.). In this stage the embryo is composed of sixteen cells of the sixth generation and eight of the fifth.

The *Fourth Quartet* ($a^{5.4}$– $d^{5.4}$) divides, forming $a^{6.7}$– $d^{6.7}$ and $a^{6.8}$– $d^{6.8}$, Plate I. Fig. 3. Here, as in the other divisions resulting in the sixth generation, the upper derivatives lie to the right of the corresponding lower derivative, and the spiral is a *right* spiral. It is a matter of importance to note that the quartet $a^{5.4}$–$d^{5.4}$, *whose cells are larger than those of its sister quartet* $a^{5.3}$–$d^{5.3}$, divides before the latter quartet does. Plate I. Fig. 3.

Third Quartet. The division of $a^{5.3}$–$d^{5.3}$ results in forming $a^{6.5}$–$d^{6.5}$ and $a^{6.6}$–$d^{6.6}$. This, like the other three, produces a *right* spiral. The division of this third quartet is begun before that of the fourth quartet is completed; likewise, before the completion of the division of this last quartet of the sixth generation, that resulting in the seventh generation begins, and this so far as followed has left spirals. Thus we see that in the cleavage of Limax there exists *an alternation in the direction of the spirals in successive generations.* The spirals of the *even* generations are right spirals, and those of the odd generations are left spirals.

Of the generations discussed, the fourth and sixth have right, the third and fifth have left spirals. This alternation of spirals apparently rests upon the more fundamental and wide-spread tendency of the spindle to take a position at right angles to that of the spindle of the previous division. This tendency can be traced from the last maturation spindle of the ovum throughout the spiral period and in some cases far into the bilateral period of cleavage, as in the development of the mesoderm in Umbrella (Heymons '93). The spiral period of cleavage presents only slight mechanical impediment to the realization of this tendency, which therefore expresses itself here in the ALTERNATION of spirals.

The system of nomenclature here employed for Limax makes it possible to correlate the two hitherto independent systems of alternation, that of the spirals of the macromeres and that of the micromeres, so often noted by writers on cell lineage (Wilson '92, pp. 378, 391, 439, and '93, p. 600). The alternation is now reduced to a single system, based on generations, which harmonizes all of the cleavages of spiral character.

The law of alternation of spirals in successive generations is, I believe, applicable to all forms of spiral cleavage. At the present time we have two extensive papers of a recent date discussing cell lineage. That of Wilson ('92) carries the discussion through the fifty-eight-cell stage of Nereis, and that of Heymons ('93) through the ninety-one-cell stage of Umbrella. In both of these cases the law of alternation of spirals applies *without a single exception, if the spirals are named on the basis proposed in this paper.* According to Wilson ('92, p. 439), Conklin ('91, '92) has found in the cleavage of Crepidula a close resemblance to that of Nereis. Lillie ('93) has found a corresponding agreement in the cleavage of Unio. The law of alternation of spirals will then apply to Crepidula and Unio in so far as they conform to the cleavage of Nereis. In Nereis, Umbrella, and Limax we have forms presenting diverse conditions of development. We have one annelid, and two mollusks of widely separated genera, one land and two marine forms. In Nereis and Umbrella there is a large amount of yolk of a different nature and distribution in the two forms. They also present free larval stages, with different degrees of precocious development. In Limax there is very little food-yolk, and cleavage is almost equal.

The free larval stage is suppressed and the spiral period of cleavage persists for a long time, the fundaments of the organs appearing comparatively late in development. In the matter of the envelopes of the egg, the three forms present very diverse conditions; yet in all these widely differing forms we find no break in the regular alternation of spirals in successive generations as I have defined them. Previous to the publication of Wilson's paper ('92) on Nereis, which has given such an impetus to the study of cytogeny, the results of a number of investigations appeared dealing more or less fully with the phenomena of spiral cleavage. Neither confirmation nor contradiction of an alternation of spirals implied or expressed in these papers can have the weight of the more recent work on this subject. The examination of the works of Lang ('84), Kowalevsky ('83), Blochmann ('81), Rabl ('79), Bobretsky ('77), and Fol ('75, '76) has convinced me, however, that the principle of alternating spirals is of wide, if not universal, applicability among the various forms studied by these authors.

The number of cases in which the law is contradicted is surprisingly small. I shall deal with them more fully in my final paper, and for the present shall merely call attention to the nature of the more important contradictions. Some of them rest upon interpretations of the relations of cells which by implication or explicit statement of the author are conjectural, as in Kowalevsky's ('83) earlier and Metcalf's ('93) later work upon Chiton. Another kind of contradiction is found in two special cases: (1) in the condition leading to the eight-cell stage of Planorbis, — a form with sinistral shell, — as described by Rabl ('79, Taf. XXXII. Figs. 9, 10); and (2) in the corresponding stage of Janthina — a form with dextral shell (Fischer, '80–'87, p. 775) — according to Haddon ('82, Plate XXXI. Fig. 6). In both these cases, the spiral of the fourth generation, instead of being a right one, as in all other cases examined, is apparently a left one. These, however, do not necessarily present exceptions, for an alternation of spirals in successive generations may obtain even here, since the principle of alternation does not necessarily imply that the right spirals should in all forms give rise to the even generations. In other words, we may have in these two forms cases of "reversed cleavage." The decision of this point must be held in abeyance until further investigation can be made on these forms. Still other contradictions belong to a class which ceases to be contradictory when the author's figures are relabelled, and thereby become better reconciled with each other as well as with the principle of the alternation of spirals. One such case is found in Lang's work on Discocœlis ('84, Taf. XXXV. Fig. 6), and another in Blochmann's paper on Neritina ('81). With the latter I shall deal in this paper. It is only fair to note that Blochmann's work was that of a pioneer in the field of cell lineage, and it is therefore not strange that later observers, in the light of comparative study, find their results at variance with his; as Wilson and Conklin have in reference to the origin of the "cross" (Wilson, '92, p. 441). I shall take great liberties with Blochmann's work, and shall endeavor to show that the cleavage of Neritina, as *figured* by him, conforms to the law of alternation of spirals, and shall give such arguments as I can from internal evidence and theoretical considerations to support my interpretation; but it is to be remembered that my conclusions remain hypothetical until verified or disproved by renewed observation. Figures 7–12 (Plate II.) are reproductions in outline respectively of Figures 45–48, 50, and 51 (Taf. VII.) of Blochmann's paper ('81), with *his* labelling outside the limits of the figures and *my own* inside the same limits. No exception is taken to his interpretation until the stage of Figure 10 is reached. Here I must differ radically from the author's interpretation of the relations of the two quartets a_3–d_3 and $a_2{}^{\mathrm{I}}$–$d_2{}^{\mathrm{I}}$. The designations of the cells a_3, $d_2{}^{\mathrm{I}}$, d_3, $c_2{}^{\mathrm{I}}$, c_3, $b_2{}^{\mathrm{I}}$, b_3, $a_2{}^{\mathrm{I}}$, must all be shifted one place to the right; i. e. in the direction of the hands of the watch, as indicated by the long arrows outside the limits of the figure in Figure 10. In my interpretation the quartet a_3–d_3 is the quartet designated as $a_2{}^{\mathrm{I}}$–$d_2{}^{\mathrm{I}}$, and *vice versa*. The change is made upon the following grounds.

(1.) The spindle in the cell b, for example, Figures 8, 9, indicates that the cell b_3 (Fig. 8, = my $d^{6.2}$) will lie above and to the *right* of the cell b (my $d^{6.1}$), and perhaps higher (Figs. 9, 10) than the upper derivative (my $d^{6.4}$) of the cell b_2 (my $d^{5.2}$), and that it will lie in contact with that derivative ($d^{6.4}$) and with the *lower* derivative ($a^{6.3}$) of the cell a_2 (my $a^{5.2}$). This is my interpretation of the position of the cell b_3, as foreshadowed by the spindles of Figures 8, 9. However, in Figure 10 Blochmann has placed the cell b_3 on the *left* side of the cell b, and in contact with $a_2{}^{\mathrm{I}}$ and b_2, a position directly contradictory to that indicated by the position of the spindle of the cell b in Figures 8, 9.

(2.) The spindle of the cell b_2 in Figures 8, 9, indicates that the products of its division will lie upon the upper left side of the cell b, the upper derivative being in contact with the cell b_3 and with the lower derivative. Blochmann's interpretation, on the other hand, throws the upper derivative completely out of the quadrant of the cell b, and over upon the cell c of an adjoining quadrant. The position of the cells a_3–d_3 and a_2^{I}–d_2^{I}, as figured by Blochmann in Figure 10 can be explained only on the assumption of a rotation of both sets of spindles (or of the upper derivatives of the spindles) as shown in Figure 9 about ninety degrees to the left. The fact that he has not observed such a rotation renders its existence all the more improbable.

There remains, however, important evidence in favor of Blochmann's view, namely the presence in the cells a_2 and c_2 of "eine Anhäufung von kleinen stark lichtbrechenden Körnchen." After the cell divisions indicated in Figures 46, 47 (Plate II. Figs. 8, 9), *all* of these granules are found in the cells a_2^{I} and c_2^{I}, hence the idea of their derivation from the cells a_2 and c_2. Such a view must presuppose (1) that in the equal division of the cells a_2 and c_2 all of these granules go to *one* of the supposed daughter cells, i. e. to a_2^{I} and c_2^{I}; (2) that granules similar to those of the cells a_2 and c_2 cannot arise in other cells derived, like a_2 and c_2, from the macromeres. If, on the other hand, the view advanced here as to the interpretation of Figure 48 (Plate II. Fig. 10) is correct, we may suppose that in the equal division of the cells a_2 and c_2 the granules accumulated in them were shared by the two daughter cells a_2 and a_3, c_2 and c_3 (using Blochmann's designations, but not his interpretation), and thus the granules were divided and became less conspicuous. At the same time the cells a_2^{I} and c_2^{I} of the third set of micromeres, originating, as I believe they do, from the macromeres b and d, show granules similar to those of the cells a_2 and c_2 of the second set of micromeres. This may afford an escape from the dilemma as to the relation of these groups of cells in which Blochmann is placed by the contradictory evidence afforded on the one hand by the position of the spindles, on the other by the presence of the granules in the cells.

With regard to the origin of the cells of the quartet a_2^{II}–d_2^{II} of Figure 50 (Plate II. Fig. 11), I wish to present a view which differs from that of the author. As the nomenclature indicates, he derives this group from his quartet a_2^{I}–d_2^{I} of Figure 48 (Plate

II. Fig. 10). There are indications, however, that they were really derived from the apical quartet a_1–d_1; for (1) their nuclei are nearer those of the apical quartet; (2) the cells of the apical quartet are much smaller after the cells a_2^{II}–d_2^{II} appear than before; (3) a_2^{I}–d_2^{I} have just arisen by a recent division, whereas some time has elapsed since the first division of the apical quartet, Figure 45 (Plate II. Fig. 7). If this interpretation holds, the cells a_1 and d_2^{II} result from the division of a_1, while b_1 and a_2^{II} come from b, etc. The inner part of the "cross" would thus arise from the first group of micromeres and the outer part from the third group. These suggested changes reduce the cleavage of Neritina to complete agreement with that of Nereis, Umbrella, and Limax.

Wilson ('92, p. 439) compares the cleavage of Nereis with that of the polyclad Discocœlis, and also with that of the gasteropods — taking Neritina and Crepidula as types — as follows: "Up to a late stage in the spiral period (twenty-eight cells) every individual blastomere and every cell division [in Nereis] is represented by a corresponding blastomere and a corresponding cell division in the embryo of the polyclad and in that of the gasteropod." This statement must imply, it seems to me, some other interpretation of the cleavage of Neritina than that given by Blochmann himself, although Wilson makes no statement to that effect, but on the contrary says (p. 442), "It is impossible to explain the differences between the annelidan and molluscan cross by assuming inaccuracy of observation on Blochmann's part, since the pole cells of the lateral arms show a peculiar granulation that may be seen in the parent cells ($a^{2.2}$, $c^{2.2}$) from which they rise." The reduction of Neritina to agreement with Nereis and Umbrella in the manner I have suggested brings it also into harmony with the law of alternation of spirals, and this affords another presumption in favor of the correctness of the revision here proposed. That the spirals do alternate in Neritina can be seen on an examination of the short arrows indicating my interpretation of the genetic relation of the cells of Neritina (Plate II.). The arrows show the relation of the cells, the head of the arrow in every case lying in the derivative which, according to my interpretation, is the upper one. The following table will assist in the comparison of the two interpretations and the determination of the spirals.

Revised.				Blochmann.
Spiral.	Nomenclature of Cells.	Generation.	Cell Stage.	Nomenclature of Cells.
Left . . .	a^3, b^3, c^3, d^3	3	4	a, b, c, d
Right . .	$\left\{ \begin{matrix} a^{4.2} \\ a^{4.1} \end{matrix} > a^{3} \right\}$	4	8	$\begin{matrix} a_1 \\ a \end{matrix} > a$
Left . . .	$\left\{ \begin{matrix} a^{5.4} \\ a^{5.3} \end{matrix} > a^{4.2} \right\}$	5	16	$\begin{matrix} a_1 \\ a_1^{\mathrm{I}} \end{matrix} > a_1$
Left . . .	$\left\{ \begin{matrix} a^{5.2} \\ a^{5.1} \end{matrix} > a^{4.1} \right\}$		12	$\begin{matrix} a_2 \\ a \end{matrix} > a$
Right . .	$\left\{ \begin{matrix} a^{6.8} \\ a^{6.7} \end{matrix} > a^{5.4} \right\}$	6	28	$\begin{matrix} a_1 \\ d_2^{\mathrm{II}} \end{matrix} > a_1$
Not figured.				
Right . .	$\left\{ \begin{matrix} a^{6.4} \\ a^{6.3} \end{matrix} > a^{5.2} \right\}$		24	$\begin{matrix} a_3 \\ a_2 \end{matrix} > a_2$
Right . .	$\left\{ \begin{matrix} a^{6.2} \\ a^{6.1} \end{matrix} > a^{5.1} \right\}$		20	$\begin{matrix} d_2^{\mathrm{I}} \\ a \end{matrix} > a$
Left . . .	$\left\{ \begin{matrix} a^{7.8} \\ a^{7.7} \end{matrix} > a^{6.4} \right\}$	7	36	$\begin{matrix} a_3 \\ d_3^{\mathrm{I}} \end{matrix} > a_3$
Left . . .	$\left\{ \begin{matrix} a^{7.4} \\ a^{7.3} \end{matrix} > a^{6.2} \right\}$		36	$\begin{matrix} d_2^{\mathrm{III}} \\ d_2^{\mathrm{I}} \end{matrix} > d_2^{\mathrm{I}}$

Only two spiral cleavages of the seventh generation are figured.

It will be noted that in Plate II. Fig. 10, the order in position of the quartets of the sixth generation taken from the vegetative toward the animal pole is as follows: $a^{6.1}-d^{6.1}$, $a^{6.3}-d^{6.3}$, $a^{6.4}-d^{6.4}$, and $a^{6.2}-d^{6.2}$, instead of $a^{6.1}-d^{6.1}$, $a^{6.2}-d^{6.2}$, $a^{6.3}-d^{6.3}$, and $a^{6.4}-d^{6.4}$, as in Limax, Plate I. Fig. 2. This change in the succession of quartets is due to the fact that in Neritina the quartet $a^{5.2}-d^{5.2}$ by virtue of the spiral occupies a position in the furrows between the macromeres $a^{5.1}-d^{5.1}$. Therefore, when the cleavages resulting in the sixth generation take place, the upper derivatives ($a^{6.2}-d^{6.2}$) of the quartet $a^{5.1}-d^{5.1}$ come to occupy a position nearer the animal pole than the upper derivatives ($a^{6.4}-d^{6.4}$) of the quartet $a^{5.2}-d^{5.2}$. The application of the system of nomenclature proposed in this paper is not thereby involved in difficulty, for the designation of the daughter cells is in all cases predetermined by that of the mother cell, according to the basis set forth on page 186, the upper derivative in every case receiving the even exponent and the lower one the odd. Thus, notwithstanding the secondary changes induced in the position of the quartets by the accumulation of yolk in the basal quartet, the cells in Neritina retain the same nomenclature that is given to the homologous cells of a form such as Limax, presenting the typical undisturbed superposition of quartets.

In all the literature examined there occurs but a single case where the position of an indicated *spindle* contradicts the principle of alternation of spirals. This is found in Lang ('84, Taf. 34, Fig. 20) in the division of the cells ae_1–de_1, forming ae_1–de_1 and ae_6–de_6. Little can be said with regard to this except that we do not know the full nuclear history of this cleavage, and that it occurs at the close of the spiral period, immediately over the group of "Scheitelzellen" that has just sunk below the level of the remaining ectoderm. This may have produced secondary modifications in the direction of the spiral.

It remains for me to speak of the influence of yolk upon cleavage. Reference to Plate I. Fig. 2, shows that in Limax the cell $b^{5.3}$ belonging to the quartet of this generation, which is the last to divide, is a member of the *smallest* quartet of the fifth generation. It will further be seen that the order of the division of the quartets, viz. first, second, fourth, third, is also the order of size from largest to smallest, the quartet of largest cells, i. e. those presumably with the greatest amount of yolk being the first to divide in this generation, as it was also in the preceding generation. This phenomenon is by no means confined to Limax. It is found in a great variety of forms, and the greater the amount of the yolk the greater seems to be the tendency of the cells of the yolk-laden quartet to divide before those of the smaller quartets. This can be illustrated by a comparison of Figure 1 (Plate I.), which shows the egg of Limax approaching the sixteen-cell stage, and Figure 7 (Plate II.), which shows Neritina approaching the same stage. In Limax there is little yolk, and the cleavage of the two quartets is almost coincident. In Neritina, however, where the yolk is more abundant, the lower quartet has divided, and its nuclei have assumed a "resting condition" before the cleavage of the upper quartet has fairly begun. Thus we have a well marked twelve-cell stage. The same tendency of the yolk-laden cells to cleave before the others is seen in the later stages of Neritina, and indeed in many forms of Molluscan cleavage. It is also found in Nereis and Discocœlis. It is not, however, confined to the spiral type of cleavage, for in Echinocyamus (Théel '92), where the cleavage is of the radial type, we find the meridional cleavages, which divide the quartets into "octets," starting with the fourth cleavage (eight- to sixteen-cell stage) at the vegetative pole, and reaching the apical quartet of the animal pole in the sixty-cell stage. Not only does the quartet having the largest cells divide first, but where there is an inequality in the size of the cells of a quartet, the largest cell or cells may divide first, as is the case in Discocœlis (Lang '84) and Unio (Lillie '93). In view of these facts I wish to raise the question as to the applicability to the individual cells of cleaving eggs of the law first formulated by Balfour ('75) and concisely expressed in his "Comparative Embryology" ('80, Vol. I. p. 95), as follows: "Where the yolk spherules are fewest, the active protoplasm is necessarily most concentrated, and we can lay down as a general law that the velocity of the segmentation in any part of the ovum is, roughly speaking, proportional to the concentration of the protoplasm there; and that the size of the segments is inversely proportional to the concentration of the protoplasm. Thus the segments produced from that part of an egg where the yolk spherules are most bulky, and where therefore the protoplasm is least concentrated, are larger than the remaining segments, and their formation proceeds more slowly."

It is true that, of two *eggs* otherwise similar, the one with the larger amount of yolk in general cleaves more slowly. For example, Umbrella, which has a large amount of yolk, requires four days to reach the stage attained by Limax in one day. But of two *cells* of Limax or Umbrella during the cleavage period, that one is the *first* to divide which is the larger and presumably has the greater amount of yolk, and which in Balfour's terms has its protoplasm less concentrated. Not only this, but in the cases cited the greater the amount of the yolk the greater is the tendency of the division of the yolk-laden cell to precede that of the cell with less yolk. There are, to be sure, many cases where Balfour's law actually applies, as in the frog's egg; but do not the cases cited above, belonging as they do to numerous and widely distributed classes of animals, form an important exception to the law as he has formulated it? A paradox is thus presented. Yolk appears to delay cleavage in the cells of the frog's egg, to hasten it in the cells of the snail's egg. Yolk also appears to delay the development of an organism as a whole (cf. Limax and

Umbrella) while it may (in Limax and Umbrella) at the same time apparently hasten the cleavage of those *cells* of the organism in which it is more abundant. This apparent conflict of statements has its foundation in the hypothesis that the amount of yolk alone is the decisive factor in the determination of the rapidity of cleavage. But there are other factors to be considered, especially the *quality* of both yolk and protoplasm, and in these there may ultimately be found some solution of the difficulty. In the case of the presumably undifferentiated blastomeres of the cleavage stages of Limax (and Umbrella) the difference in the rapidity of cleavage is apparently correlated with the greater or less absolute amount of protoplasm in the individual cells. The amount of protoplasm, in turn, is dependent on both the quality of the yolk and the activity of the protoplasm. The yolk, by contributing to the amount of protoplasm in the larger cells, may thus indirectly hasten their division. In this, however, the appropriation of the yolk by the protoplasm is the important factor, for in case the protoplasm fails to appropriate the yolk with sufficient rapidity, the division of the yolk-laden cell may be delayed as in the frog's egg. This delay may depend on either one or both of the two factors, — quality of protoplasm and quality of yolk. These same factors probably determine the differences in the rates of cleavage of different eggs. While this does not afford a solution of the difficulties encountered in attempting to harmonize the facts here presented with Balfour's law of cleavage as influenced by yolk, future inquiries in the direction suggested may lead to a better understanding of the factors determining the nature of cleavage.*

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EXPLANATION OF PLATE I.

Figures 1–4, Limax, drawn with camera lucida.

Figure 1. Eight-cell stage from anterior end, × 375; *p.g.*, polar globules; *s.c.*, segmentation cavity.

" 2. Twenty-four-cell stage from right side, × 375.

" 3. Twenty-five-cell stage from the animal pole, × 375.

" 4. Same egg from vegetative pole, × 375.

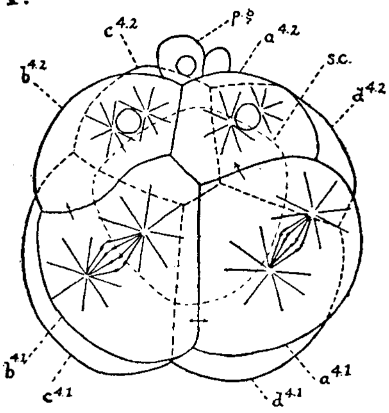
Figures 5, 6, Nereis after Wilson ('92).

" 5 After Plate XIV. Fig. 21, "Rear view of twenty-two-cell stage. Division of *X*, spindles of c^3, d^3."

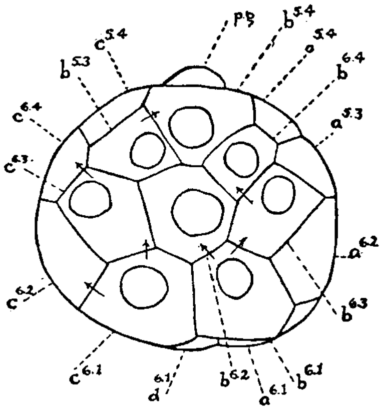
" 6. After Plate XV. Fig. 25, "Thirty-two- (four-) cell stage, right side-view. Third spiral cleavage of a^1, b^1, c^1, d^1, in progress."

PLATE I.

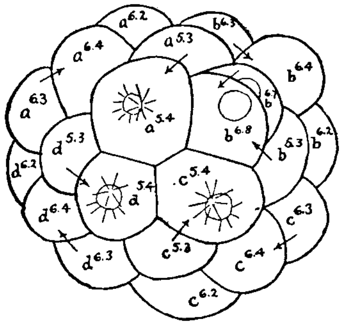
1.


$c^{4.2}$
p.♀
$a^{4.2}$
$b^{4.2}$
s.c.
$d^{4.2}$
$b^{4.1}$
$c^{4.1}$
$d^{4.1}$
$a^{4.1}$

2.


P.♀
$b^{5.4}$
$c^{5.4}$
$a^{5.4}$
$b^{5.3}$
$b^{6.4}$
$c^{6.4}$
$a^{5.3}$
$c^{6.3}$
$a^{6.2}$
$c^{6.2}$
$b^{6.3}$
$c^{6.1}$
$d^{6.1}$
$b^{6.2}$
$a^{6.1}$
$b^{6.1}$

3.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$a^{5.3}$
$b^{6.4}$
$a^{6.3}$
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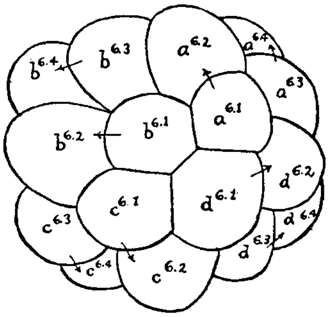
$b^{6.1}$
$d^{5.3}$
$b^{6.8}$
$b^{5.3}$
$b^{6.2}$
$d^{6.2}$
$d^{5.4}$
$c^{5.4}$
$d^{6.4}$
$c^{6.3}$
$d^{6.3}$
$c^{5.3}$
$c^{6.4}$
$c^{6.2}$

4.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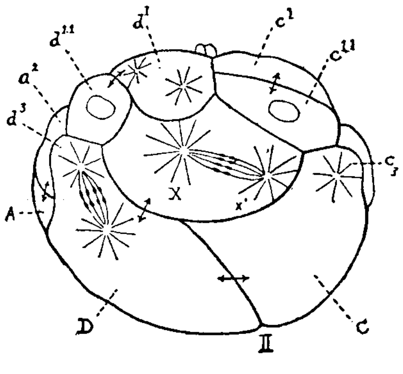
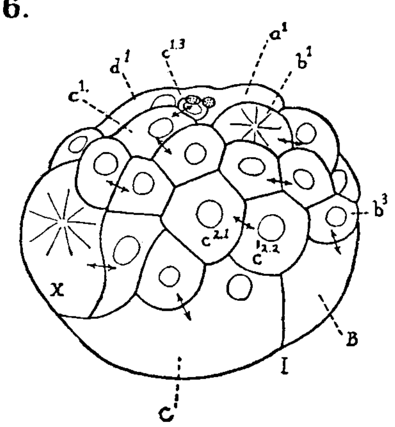
$b^{6.3}$
$a^{6.2}$
$a^{6.4}$
$a^{6.3}$
$a^{6.1}$
$b^{6.2}$
$b^{6.1}$
$d^{6.2}$
$c^{6.1}$
$d^{6.1}$
$d^{6.4}$
$c^{6.3}$
$d^{6.3}$
$c^{6.4}$
$c^{6.2}$

5.


$d^{1.1}$
d^{1}
c^{1}
$c^{1.1}$
a^{2}
d^{3}
c_{3}
A
X
x'
D
II
C

6.


a^{1}
$c^{1.3}$
d^{1}
b^{1}
c^{1}
b^{3}
$c^{2.1}$
$c^{1.2}$
X
B
I
C

EXPLANATION OF PLATE II.

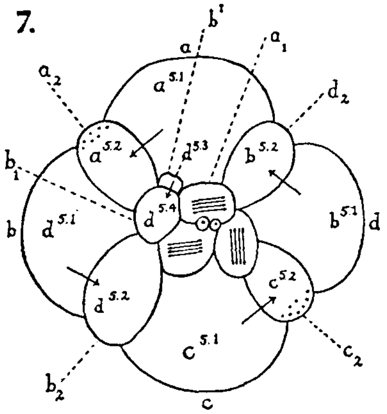
Neritina after Blochmann ('81).

The arrows, indicating the derivation of cells, and the nomenclature placed within the limits of the figures are mine; the rest of the nomenclature is reproduced from Blochmann's figures. It is to be observed that his lettering, a, b, c, d, is from right to left, whereas my own is that generally accepted, — from left to right. The explanation of these figures is taken from Blochmann, and the term "generation" is used in the sense in which he has employed it.

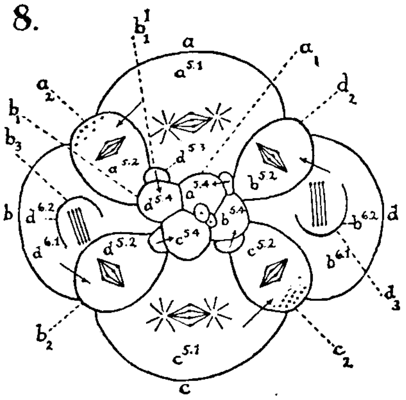
Figure 7. Taf. VII. Fig. 45. "Formation of the cells of the sixth generation, a_1^{I} b_1^{I} c_1^{I} d_1^{I}. *Rbl*, polar globules."
" 8. Taf. VII. Fig. 46. "Formation of the cells of the seventh and eighth generations, a_3 b_3 c_3 d_3 and a_2^{I} b_2^{I} c_2^{I} d_2^{I}."
" 9. Taf. VII. Fig. 47. "The same stage in profile."
" 10. Taf. VII. Fig. 48. "Completed twenty-four-cell stage." The long arrows, indicating a change of interpretation, are mine.
" 11. Taf. VII. Fig. 50. "Twenty-eight-cell stage; a_2^{II} b_2^{II} c_2^{II} d_2^{II}, cells of the ninth generation."
" 12. Taf. VII. Fig. 51. "Thirty-six-cell stage; vz derived from a_2^{II}, vz_1 from c_2^{I} [my $b^{7 \cdot 3}$], d_2^{III} from d_2^{I}, a_3^{I} from a_3, etc.

PLATE II.

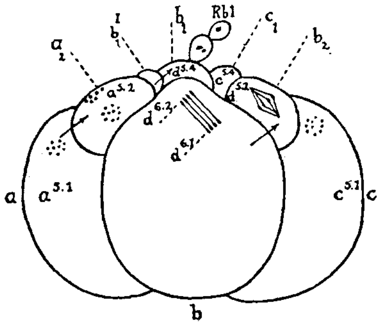
7.


b'
a
a1
a2
a5.1
d2
b1
a5.2
d5.3
b5.2
b
d5.1
d5.4
b5.1
d
d5.2
c5.2
c5.1
b2
c2
c

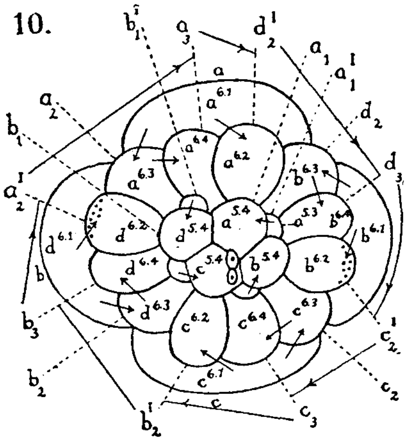
8.


b1'
a
a1
a5.1
a2
d2
b1
b3
a5.2
d5.3
b5.2
b
d6.2
d5.4
a5.4
b5.4
b6.2
d
d6.1
d5.2
c5.4
c5.2
b6.1
d3
b2
c5.1
c2
c

9.


b1'
b1
Rb1
c1
b2
a2
d5.4
c5.4
a5.2
c5.2
d6.2
d6.1
a
a5.1
c5.1
c
b

10.


b1'
a3
d2'
a1
a1'
a
a6.1
a2
d2
b1
a6.4
a6.2
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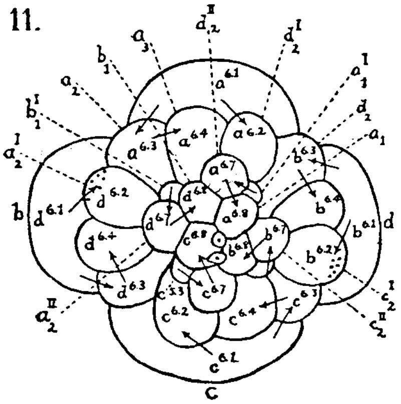
b6.3
d3
a2'
d6.1
d6.2
d5.4
a5.4
a5.3
b6.4
b6.1
b
d6.4
c5.4
b5.4
b6.2
b3
d6.3
c6.3
c6.2
c6.4
c2'
b2
c6.7
c2
c
c3
b2'

11.


d2II
a3
d2I
b1
a1I
a2
a6.1
d2
b1I
a1
a6.4
a6.2
a6.3
b6.3
a2I
a6.7
b
d6.1
d6.2
d6.8
b6.4
d
d6.7
a6.8
b6.1
d6.4
c6.8
b6.8
b6.7
b6.2
d6.3
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c6.3
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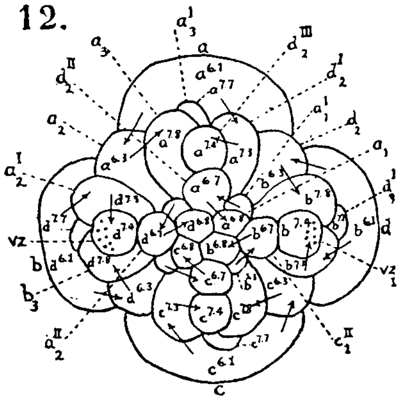
c6.2
c6.4
c2II
c6.1
c

12.


a3I
a3
a
d2III
d2II
a6.1
a7.7
d2I
a2
a1I
d2
a7.8
a7.4
a1
a2I
a6.3
a7.3
b6.3
d1I
d7.3
a6.7
b7.8
d7.7
d7.4
d6.7
a6.8
b6.7
b7.4
d
VZ
b
d6.1
d7.8
c6.8
b6.8
b7.7
b6.1
VZ1
b3
d6.3
c6.7
c6.3
c7.3
c7.4
c7.8
a2II
c7.7
c1II
c6.1
c

VIII.

FURTHER OBSERVATIONS UPON THE OCCURRENCE OF DIAMONDS IN METEORITES.

By Oliver Whipple Huntington, Ph. D.

Presented October 11, 1893.

Ever since Haidinger, in 1846, described a cubic form of graphite in the Arva iron, and Rose suggested that the crystals were pseudomorph after diamond,* the possibility of finding the gem itself in meteorites has been conceived.

In 1886, H. Carvill Lewis, after his study of material from the greatest depths of the South African diamond mines, predicted the discovery of diamonds in meteorites.† Hence it was no great surprise when graphite having the hardness and form of the diamond was found by Jerofeieff and Latschinoff in the Novo Urei meteorite.‡ No colorless material, however, seems to have been found till E. Weinschenk described, in 1889, a minute quantity of transparent grains from the Arva iron, hard enough to scratch the ruby, and burning in oxygen to form carbonic acid gas.§

A fresh interest was added to the study of the subject two years ago when Dr. A. E. Foote brought numerous pieces of the Cañon Diablo iron from Arizona, and Professor Koenig of Philadelphia announced that a piece of it contained diamonds, his statement being based upon the appearance of a black vitreous substance lining a cavity, and having a hardness beyond the sapphire. Dr. Foote says in his paper on the subject, "The most interesting feature is the discovery for the first time of diamonds in meteoric iron." ‖ He then refers to the cubic form of graphite in the Arva iron, described so long ago by Haidinger, and the cliftonite found by Fletcher in the Youndegin iron, but makes no mention of Weinschenk's description of colorless transparent diamonds in the Arva iron.

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* Pogg. Ann., Bd. LXVII. pp. 437–439, 1846.

† British Association, 1886, p. 667.

‡ Verhandl. der kais. russ. Mineral. Gesellschaft, 2d Series, Vol. XXIV. p. 263, 1888.

§ Annalen des k.-k. naturhistorischen Hofmuseums, Vol IV. p. 93, 1889.

‖ Proceedings of the American Association for the Advancement of Science, Vol. XL. p. 4.

The Mineral Cabinet of Harvard University was presented, through the liberality of Francis Bartlett, Esq., with one of the original masses of the Cañon Diablo meteorite, and it was at once examined for diamonds. A piece weighing one hundred grams was dissolved in acid, and, after the usual process of getting rid of the carbon, silica, etc., a small quantity of fine powder was separated by its higher specific gravity and examined under the microscope. It appeared to be made up of dark and light grains, the latter showing unmistakably the lustre of the diamond. The colorless particles were separated mechanically upon the stage of the microscope, and looked to the eye like white beach sand. One of these grains was mounted in the point of a metallic lead pencil, and it was found that, though so small, it would readily cut glass with the characteristic singing noise of a glass-cutter's diamond, and it would also readily mark upon a polished sapphire. There was not enough of the clear material obtained at the time for a chemical test, and on account of the association of the diamond grains with amorphous carbon, such a test would not have been conclusive without a perfect mechanical separation.

This seemed at the time sufficient proof that the material was diamond, and a portion of it was exhibited before the meeting of the American Academy of Arts and Sciences on May 11, 1892, and at that time the author showed a large nodule of graphite from the Sevier County iron and said: —

"As is well known, graphite separates from melted cast iron when it slowly cools, and the connection of these masses with the iron meteorites indicates that they also were formed by the slow cooling of masses of melted iron, very possibly thrown up by volcanic action from the interior of some planet. The high specific gravity of the earth suggests the conjecture that its interior is a mass of iron, and the metallic iron which has been found in the deep-seated eruptive rocks, as in Greenland and the South of France, gives support to the hypothesis that these rocks may be the matrix of the diamond, and that the diamond crystals may have separated during slow cooling from the melted metal forced up from below.

"Thus: —

"Graphite separates out from meteoric iron. It also separates during the cooling of cast iron.

"Graphite is further found associated with the iron of the deep-seated rocks.

"Graphite, crystallizing in the form of diamond, is found in meteoric iron. Diamonds are also found in meteoric iron.

"The greatest deposits of native diamonds appear to have come from great depths.

"Does it not appear plain that the meteoric diamonds, which are obviously in their original matrix, may explain the origin of the terrestrial diamonds?

"My object has been merely to point out a possible relation, and not to advocate a theory, but in this relation we have a clue which may possibly lead to a solution of one of the most obscure problems of mineralogy."

It was further suggested that pressure might be a determining factor in the crystallization of carbon. At the time this seemed a somewhat large assumption to make from so small data, but since then M. Moissan has followed up the same idea by most interesting experiments, in which he finds that carbon can be made to crystallize *out of melted wrought iron in the form of diamond if the iron* is allowed to cool under pressure; as is the case when the melted metal expands in setting against the crust formed by quenching the exterior of the mass with water.* May it not be that, if we could reach thus a pressure commensurate with that produced by the crust of the earth, the resulting diamonds would attain the size and perfection of those now found in the famous diamond fields of South Africa?

In December, 1892, M. C. Friedel,† apparently not having seen the papers published by the author seven months before, made a thorough examination of some of the Cañon Diablo iron. The diamonds that he isolated were of the carbonado variety, and in order finally to prove that the black grains were diamond he burnt a portion in oxygen. Thus he proved chemically that the substance was carbon, and since the hardness was beyond the ruby he considered it sufficiently determined that it belonged to the variety diamond. The proof of the hardness of the diamond, however, does not rest with the fact that diamonds will scratch the sapphire or the ruby, since this may be done by other substances, notably "carborundum," but diamond alone will cut diamond, and this test had not been applied to the material from the Arva, Novo Urei, or Cañon Diablo meteorites. Especially since the work of Daubrée and others has shown how numerous the allotropic forms of carbon may be, varying in hardness, specific gravity, and other physicial characters, it seemed of value to get a more accurate determination of the hardness of this new material, since no distinct crystals had been observed.

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* Comptes Rendus, Tome CXVI. No. 6, Feb. 6, 1893, p. 218.

† Bulletin de la Société Française de Minéralogie, Tome XV. No. 9, December, 1892, p. 258.

At the suggestion of Mr. George F. Kunz, the author undertook to dissolve many pounds of the Cañon Diablo iron, in order to obtain enough diamond dust to use at the Columbian Exhibition for cutting and polishing rough diamonds, thus demonstrating in a practical way the fact that we have true diamonds in meteorites.

A method of dissolving iron slightly different from that described by the author in "Science"* was adopted, in order to find if possible the paragenesis of the diamond material. About two hundred pounds of the iron was examined, and the most promising pieces were dissolved. The object of working on so large a scale was twofold. In the first place, to obtain sufficient material for the practical test of cutting and polishing rough diamonds, and in the second place to discover how the substance occurred, and whether it crystallized in the usual form. Of course there was also a possibility, though not a probability, of happening upon a crystal of considerable size. The specimens of iron selected were successively suspended by a platinum wire in a platinum bowl, filled with hydrochloric acid nearly saturated with chloride of iron and then slightly diluted with water. The iron was made the positive pole of a battery consisting of twelve gravity cells, the bowl forming the other electrode. When the conductivity of the solution was properly adjusted by means of the chloride of iron it was found that only the pure iron of the meteorite would dissolve, thus setting free the plates of schreiberseit and taenite, as well as the graphite and other impurities, bringing out the crystalline structure of the meteorite in wonderful perfection.

A partially dissolved piece is shown a little less than the natural size in Figure 1. Unfortunately, the sketch does not bring out the plates as prominently as they appear in the specimen, and the differences of tint, which are very striking in the original, cannot be reproduced in a black and white print. If the acid was too strong, or the temperature of the solution slightly increased, all the distinction of parts at once disappeared, and it dissolved *en masse*, leaving a great quantity of slime in the bottom of the dish.

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* Vol. XX. No. 492, July 8, 1892.

The iron was dissolved in two- or three-ounce pieces, and it at once appeared that there was a wide variation in its composition. Most of it contained no diamonds whatever. One piece, however, in the process of dissolving showed an irregular vein running through it consisting of a white vitreous substance varying in width from a fine line to nearly four millimeters. On trying the hardness of the vein-stuff, it was found to be beyond the ruby. On further examination, it appeared to be a mixture of iron, a sulphide of iron, silica, amorphous carbon, and diamond, so that it finally had to be crushed in order to get rid of all the iron.

The hardest grains were isolated by the method described in the previous papers, and when examined under the microscope one minute but perfect octahedron of diamond was found, transparent and colorless. It was separately mounted on a microscope slide, but soon disappeared, and in its place were found only some very minute angular fragments. A second crystal was afterwards isolated, but disappeared in like manner, suggesting that they had been formed under pressure, and when exposed in a warm room had exploded.

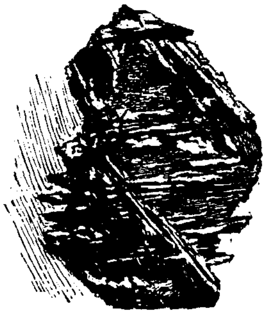

FIG. 1.

This called to mind the fact that broken diamonds are so often found in the South African mines, though the cases may not be analogous, since in the latter instance the fragments have never been found associated.

About half a carat of diamond powder was finally obtained, being separated by its specific gravity from a very large quantity of amorphous carbon. The particles varied from colorless through yellow and blue to black. Many of them appeared to be angular fragments, though some of them looked not unlike hyalite except for their more brilliant lustre. Several perfect little octahedrons were found that did not break up, and Figure 2 is an exact reproduction of a drawing of one of these crystals, traced through a camera lucida attached to a microscope. The original specimen measured only a little over a hundredth of an inch in diameter, but viewed through a two-thirds objective it showed distinctly the hexakis octahedral planes, the curved edges, striations, etc. exactly as seen in the drawing. Unfortunately, the print cannot show the adamantine lustre and clear water of the crystal.

A portion of the powder was sent to Mr. Kunz for the diamond-cutting experiment, but it was tried at first hastily and without success.

The author, however, was so sure of the nature of the material that he repeated the experiment in company with Mr. Kunz, on Monday, September 11, 1893, in the Tiffany Pavilion of the Mining Building of the World's Columbian Exhibition. A newly planed wheel had been provided, through the courtesy of Messrs. Tiffany & Co., but in order to make the experiment doubly sure a diamond set for cutting was placed in position on the wheel, and left there for a period of five minutes, while the wheel was making twenty-five hundred revolutions per minute. On removing the diamond it was found that there had been no appreciable shattering of the edges by friction, and that it would take a long time for its own powder to be produced in sufficient quantity to have any effect.

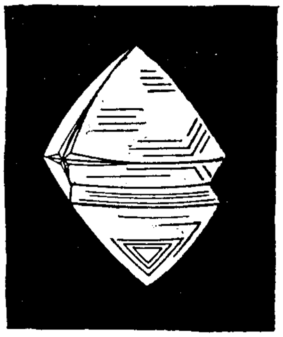

FIG. 2.

The wheel was then charged with the residue from the Cañon Diablo iron, mixed with oil in the usual way. The diamond immediately gave out a sharp hissing sound, making it apparent at once to an expert that the material was cutting, and in a few minutes it was found that a face had been ground down and polished. Two other diamonds were cut and polished in the same way. The last specimen was a complex twin, and when a projecting angle was applied to the wheel the cutting was naturally slow, but none the less effective, and in all respects the residue from the Cañon Diablo iron was found to act exactly like any other diamond powder.

Thus the combined evidence of the author's work with that of Friedel * and Moissan † establishes the fact that the Cañon Diablo iron contains true diamonds, and not any new allotropic form of carbon. It is surprising that crystals are so rare, but, as this paper shows, they do occur.

It has been suggested, since the Cañon Diablo iron has been found in such quantities, that it may have a terrestrial origin, but such an idea is at once dispelled by an examination of the exterior surface of the largest mass thus far obtained, apart from other considerations.

The mass referred to was purchased by Professor J. P. Cooke from Mr. W. W. Howell of Washington, D. C. It weighs 1087 pounds, and is at present in the Harvard Museum. It is seldom that irons which have not been seen to fall retain, at the time they are found, any of the original features of their crust, but this specimen is a marked exception. It is a roughly spherical mass somewhat flattened in one plane. One of these flattened surfaces shows signs of fusion, but is further characterized by deep pittings looking almost like bullet holes, except that it frequently happens that they are larger on the interior than at the orifice. Occasionally they are winding, but all preserve the same general direction. They vary in size from one sixteenth of an inch in diameter to two inches, and reach in some cases a depth of from three to four inches. These cannot be explained by unequal heating or by the erosive action of the air, owing to the fact just mentioned, that they are larger in the interior than at the surface. This character is shown in a reproduction of a small photograph, (Plate I. Fig. 1). The other side of the mass (Plate I. Fig. 2) shows large concave surfaces, as if pieces of six or seven inches in diameter had flaked off, or the hollows had been scooped out by the action of pneumatic drills.

For some time these two utterly different surfaces were a puzzle, but a closer examination disclosed troilite in the depths of some of the small cavities (Plate I. Fig. 1) while on the side of the larger pittings (Plate I. Fig. 2) the same mineral could be seen exposed and

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* Bulletin de la Soc. Française de Minéralogie, No. 9, Dec. 9, 1892, p. 258.

† Comptes Rendus, Tome CXVI. No. 7, Feb. 13, 1893, p. 288.

unaltered. Evidently, then, the mass must have been a meteorite, moving with its smoother face to the front, and perhaps revolving. In such a case the front would acquire the melted appearance observed, and the troilite nodules would at once fuse and become dissipated, leaving the deep and erratic cavities so characteristic of this iron, while the portion in the rear would acquire the well known pittings due to the flaking off of irregular portions. The iron is largely filled with troilite nodules, and that they did not subsequently weather away is evident from the fact that their cavities appear only on the front of the mass.

The etched surface of the Cañon Diablo iron shows great variation in the distribution of the Widmanstättian figures and troilite nodules, and the occurrence of diamond evidently varies likewise. An etched surface of a slab of this iron presented to the author by Mr. Kunz is shown by a photograph, somewhat less than half the natural size, in Plate II.

A more detailed description of these etched surfaces will appear in a subsequent paper, as the work of isolating and examining the various constituents has not yet been completed.

IX.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE, UNDER THE DIRECTION OF PROFESSOR J. P. COOKE.

DOUBLE HALOIDS OF ANTIMONY AND POTASSIUM.

BY FRANCIS GANO BENEDICT.

Presented February 14, 1894.

OF recent years an extended investigation of the nature and structure of the double haloids has been undertaken. The Rubidium and Cæsium compounds with antimonious chloride have received a good deal of attention, but an examination of the literature relative to this line of work shows marked variations in analyses as well as formulæ, ascribed to the several compounds resulting from the interaction of potassic chloride and antimonious chloride.

Accordingly an investigation was commenced to determine accurately the true nature of these salts, resulting in the preparation and analysis of four compounds.

The success of the research is greatly due to the direction and timely suggestions of Professor Cooke.

The first work that appears to have been done on these compounds is that of Jacquelaine[*] and Poggiale.[†]

In 1837 Jacquelaine[‡] described a salt formed by the union of $SbCl_3$ with 2 KCl as crystallizing in oblique rhombic prisms. His analysis is subjoined.

		Calculated.	Found.
Cl	1106.5	46.0	46.3
Sb	806.4	33.5	32.8
K	489.9	20.4	20.2
		99.9	99.3

In 1845 Poggiale[§] described two salts; i. e. one with 2 KCl or $SbCl_3 . 2 KCl$, and one with 3 KCl, or $SbCl_3 . 3 KCl$. The latter is described as deliquescent, turns yellow in the air, crystallizes in leaves, and is decomposed by water and heat. "L'eau mère abandonnée à une évaporation spontanée donne des hexaèdres composés de $SbCl_3 . 2 KCl$."

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[*] Ann. Chim. Phys., LXVI. 129.

[†] Comptes Rendus, XX. 1180.

[‡] *Loc. cit.*

[§] *Loc. cit.*

Thus confusion arises regarding the salt $SbCl_3 . 2 KCl$, as Jacquelaine states the crystalline form to be an oblique rhombic prism, while Poggiale maintains that it is cubical.

Gmelin * states, "The aqueous solution of a mixture of two atoms of chloride of potassium and one atom of terchloride of antimony yields oblique rhombic prisms (Jacquelaine)." Jacquelaine's analysis is added. Formula $SbCl_3 . 2 KCl$. "$SbCl_3 . 3 KCl$ crystallizes in laminæ; deliquescent; decomposed by boiling water (Poggiale)."

Pelouze and Fremy † state that Sb_2Cl_3 forms many double chlorides with metals, especially alkaline chlorides. The general formula for these is $(MCl)_3Sb_2Cl_3$. Chloride of potassium forms, however, two salts, $(KCl)_3Sb_2Cl_3$ and $(KCl)_2Sb_2Cl_3$.

Watts's Dictionary ‡ states: "By mixing concentrated solutions of $SbCl_3$ and alkaline chlorides, and evaporating, double salts are formed, e. g.:

$3 KCl . SbCl_3$, and $3 KCl . SbBr_3$, etc."

Storer § mentions two salts:

(*a*) $2 KCl . SbCl_3$, soluble in water without decomposition, more soluble than (*b*) in water (Jacquelaine).

(*b*) $3 KCl . SbCl_3$, deliquescent, decomposed by hot water (Poggiale).

Graham-Otto ‖ states that $SbCl_3$ forms double crystalline salts, with the chlorides of the alkaline and earthy alkaline metals.

Fehling ¶ mentions two salts:

(*a*) $3 KCl . SbCl_3$, crystallizes in leaves, and is efflorescent.

(*b*) $2 KCl . SbCl_3$, crystallizes in triclinic prisms.

Romanis ** gives the specific gravity of a salt, to which he assigns the formula $SbCl_3 . 3 KCl . 2 H_2O$, as 2.42. But no method of its preparation or reference to previous work is given. This value is given in Clarke's table of specific gravities of double salts in the "Constants of Nature."

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* Handbook of Chemistry, Cavendish edition, Vol. IV. p. 381.

† Chemie General, Vol. III. p. 160.

‡ Edition 1888, Vol. I. p. 287.

§ Dictionary of Solubilities, p. 149.

‖ Michaelis edition, Vol. II. p. 555.

¶ Neues Handwörterbuch der Chemie, ed. 1872, Vol. I. p. 670.

** Chemical News, XLIX. 273.

Rammelsberg,* in 1855, gave the crystalline form of a salt, $SbCl_3 . 2\,KCl$, as trimetric, and adds three measurements which he stated as extremely unreliable owing to the striations of the faces.

A summary of the crystallographic results obtained could be expressed as follows:

$SbCl_3 . 2\,KCl$: — monoclinic, cubic, triclinic, trimetric.
$SbCl_3 . 3\,KCl$: — crystallizes in leaves.

These variations warranted a research of these salts. Four compounds were obtained with the following composition:

$SbCl_3 . SbOCl . 2\,KCl$ [Monoclinic].
$SbCl_3 . 2\,KCl$ [Hexagonal].
$SbCl_3 . 2\,KCl$ [Monoclinic].
$SbCl_3 . 2\,KCl . 2\,H_2O$ [Monoclinic].

METHODS OF ANALYSIS.

On inspection of the above formulæ it is evident that there must be a determination of each of the four elements, Antimony, Chlorine, Potassium, and Oxygen, together with one of water of crystallization.

Antimony determinations were made by dissolving the salt in tartaric acid solution, to which a small amount of hydrochloric acid was added. The antimonious sulphide resulting from the action of a solution of hydrogen sulphide on this solution was carefully washed and dried at 220°. The method was described in detail by Professor Cooke in his paper on the Revision of the Atomic Weight of Antimony.†

The *chlorine* determination consisted in weighing the silver chloride which had been precipitated from a solution of silver nitrate by a tartaric acid solution of the salt in question. The precipitate collected on a Gooch crucible was dried at 150°. In no case was there noticed any blackening due to presence of tartaric acid, even after heating to 235°.

Potassium Determination. — Several attempts were made to precipitate the potassium-platinic chloride, but the presence of tartaric acid, necessary for the solution of the salt, caused the formation of the insoluble potassic bitartrate, which interfered materially with the process.

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* Handbuch der Krystallographischen Chemie, p. 215.

† These Proceedings, XIII. 1–114.

The method next attempted was that described by Professor J. Lawrence Smith,* for the determination of alkalies in silicates. This consists essentially in rendering the antimony insoluble by fusion with pure calcic carbonate. Then in precipitating the dissolved calcic chloride by pure ammonic carbonate and igniting the evaporated filtrate till all ammonium salts are volatilized. This gave very close results. But later a method was employed which gave at once the total amount of potassic chloride as it existed in the salt. This consisted in igniting the weighed salt in a porcelain boat in a current of dry carbon dioxide till all the volatile matter ($SbCl_3$) was given off. The ignited mass was weighed and then dissolved in water, any insoluble portion being filtered and weighed. The difference in the two weights gives the amount of soluble matter which is potassic chloride.

Oxygen was estimated directly by weighing the insoluble portion of the residue from the ignition described under the head of potassium determination. This residue is Sb_2O_3. In Professor Cooke's paper previously referred to,† there is a description of the decomposition of $SbOCl$ to Sb_2O_3.

"Meanwhile we instituted a series of experiments with a view of studying the decomposition which the oxichloride of antimony undergoes under the action of heat, in the hope that we might thus discover some method by which the amount of oxichloride of antimony in our preparations might be directly determined. . . . It appeared that the decomposition took place in two stages. The first stage of the decomposition began between 167° and 175°, but was not completed until between 260° and 280°.

"The second stage began about 320°, but requires for its completion a red heat. During both stages the chloride of antimony sublimed, and there were left in the nacelle at the close of the process beautiful crystals of Sb_2O_3. In another experiment we used crystallized $Sb_4O_5Cl_2$ prepared in the same way as the $SbOCl$, but with different proportions of alcohol and chloride of antimony. In this case the decomposition did not begin until 320°, but in other respects both the process and the products were as in the first experiment. It was quite evident that the chemical changes which took place in the two stages of decomposition we have noticed were represented by the following reactions:

First stage, $5\,SbOCl = Sb_4O_5Cl_2 + SbCl_3;$ (1)

Second stage, $3\,Sb_4O_5Cl_2 = 5\,Sb_2O_3 + 2\,SbCl_3;$ (2)

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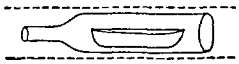
* Am. Journal of Science, Second Series, XV. 234, and XVI. 53.

† These Proceedings, XIII. 63, 64.

but *the relative weights observed in the first two experiments were* of no value, because it was evident that a no inconsiderable amount of Sb_2O_3 was lost by sublimation. Since, however, the small sublimate of oxide condensed in the glass combustion tube very much nearer the nacelle than the very much larger sublimate of chloride, we varied the apparatus in our third experiment so far as to place the nacelle in a tube of the shape represented in the accompanying figure.



"This tube was weighed with the nacelle, and was so selected that it quite closely fitted the combustion tube within which it was placed for heating, as shown in the figure by dotted lines. And it is evident that, while with this arrangement the $SbCl_3$ would be swept by the CO_2 gas into the colder portion of the combustion tube, the greater part at least of the sublimed oxide would be retained in the small tube, which was of course at each stage weighed with the nacelle as at first. . . . It was evident from this determination that the order of the decomposition was precisely that indicated by our reactions."

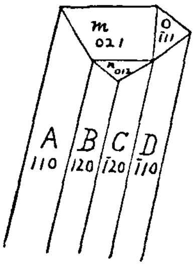
In these experiments with the double haloids very little of the Sb_2O_3 was volatilized, but proceeding in the described manner the exact amount of resulting Sb_2O_3 could be found, from which was readily calculated the per cent of oxygen.

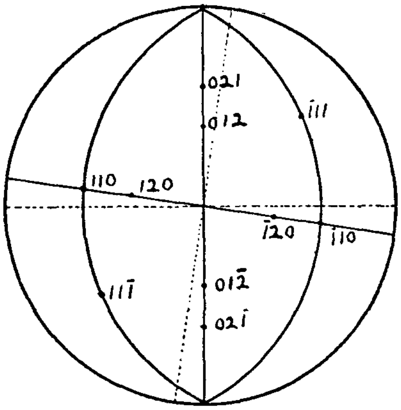
The determinations of *water of crystallization* were made in the usual way by heating in an air bath a weighed quantity of salt to constant weight at a temperature of 100–105°. This will be described more fully later.

Method of Complete Analysis.— Obviously the ignition of the salt in a current of dry carbon-dioxide affords a means of determining the total amount of each element. The salt, dried at 100°, is weighed and placed in the porcelain boat with the covering as described. Upon ignition the $SbCl_3$ volatilizes, some Sb_2O_3 also volatilizes, but is condensed on the covering tube. There is left as a residue from ignition a mixture of KCl and Sb_2O_3 (if any combined oxygen is present in the salt). Hence we see that the data are sufficient to give the exact weight of $SbCl_3$, Sb_2O_3, and KCl, from which can be calculated the total Sb, Cl, K, and O. This method, after abundant proof of its correctness, obtained by comparing the percentages of Sb and Cl resulting from ignition with the direct determination of the total Sb and Cl, was applied in all the later determinations for the estimation of potassium and oxygen. The calculated percentage of Cl and Sb from the data given were, however, invariably corroborated by an estimation of the total Sb and Cl.

The crystalline form of each salt is represented by the free hand sketches, and the accompanying stereographic projections show more accurately the mathematical relation of the planes.

$SbCl_3 . SbOCl . 2 KCl$ [Monoclinic].





$$a : b : c = 1 : 1.913 : .9877.$$
$$\beta = 81^\circ\ 4'.$$

Angles between Normals.

A B
$110 \wedge 120 = 20^\circ\ 45'$

B C
$120 \wedge \bar{1}20 = 85^\circ\ 30'$

C D
$\bar{1}20 \wedge \bar{1}10 = 20^\circ\ 45'$

A A′
$110 \wedge 1\bar{1}0 = 54^\circ\ 30'$

m n
$021 \wedge 012 = 18^\circ\ 40'$

m m′
$021 \wedge 0\bar{2}1 = 54^\circ\ 35'$

O D
$\bar{1}11 \wedge \bar{1}10 = 46^\circ\ 6'$

O O′
$\bar{1}11 \wedge \bar{1}\bar{1}1 = 44^\circ\ 0'$

These crystals were quite permanent in the air, presented no difficulty in manipulation, and allowed very close measurements with the reflecting goniometer.

The salt is decomposed immediately by hot or cold water; insoluble in hot or cold saturated solution of potassic chloride, hot or cold bisulphide of carbon, alcohol, or ligroin; soluble in hot glacial acetic acid, but on cooling a heavy white precipitate of oxichloride of antimony settles out. It is readily soluble in hydrochloric acid and a solution of tartaric acid. It will crystallize from a solution containing free hydrochloric acid. Since a determination of antimony and chlorine gave results which showed an exact ratio of one of antimony to three of chlorine, it was obvious that there must be something combined with the potassium in the salt. A determination of potassium by Smith's method left about three per cent of the salt to be accounted for. The use of dried salt eliminated water from the list of probable constituents, and chemically pure materials guarded against impurities. The fact that Professor Cooke invariably found a certain amount of oxichloride of antimony in the chloride led to a search for oxygen (combined) as the fourth element after the described method. Obviously heating the salt would drive off all the antimonious chloride, and whatever oxygen there was present was combined as the oxichloride, which upon heat left a residue of Sb_2O_3. Calculating the per cent of oxygen from the weighed Sb_2O_3 gave the required per cent. After a few preliminary experiments were tried, a series of ignitions were carefully made, with the following results.

Columns I., III., and V. contain the direct percentages of each element according to the total estimation.

I. Sb.	II.	III. Cl.	IV.	V. K.	VI.	VII. O.
Sb. Total Determination.	Sb. Calc. from Ignition.	Cl. Total Determination.	Cl. Calc. from Ignition.	K. Smith's Method.	K. Calc. from Ignition.	O. Calc. from Sb_2O_3.
43.78	43.58	39.17	38.70	14.43	14.31	2.92
44.05	43.78	39.11	38.89	14.61	14.26	2.94
*43.40	43.87	39.03	†38.58	—	14.17	2.93
43.67	44.07	39.11	38.89	—	14.50	3.04
43.62	—	38.94	—	—	14.60	—
43.69	—	—	—	—	14.60	—
43.70	43.85	39.07	38.76	14.52	14.40	2.96
43.78		**38.91**		**14.46**		**2.96**

* Probably some undecomposed oxichloride.

† This sample was undoubtedly heated too high when drying.

An examination of the above two sets of averages establishes beyond a doubt the value of the ignition method of analysis in these compounds. With these data the formula nearest approaching their values is $SbCl_3 . SbOCl . 2\ KCl$.

	Calculated * for $SbCl_3$, $SbOCl$, 2 KCl.	Found.
Sb	43.88	43.78
Cl	38.89	38.91
K	14.31	14.46
O	2.92	2.96
	100.00	100.11

It is evident, therefore, that this salt has the formula

$$SbCl_3 . SbOCl . 2\ KCl.$$

$SbCl_3 . 2\ KCl$ [Hexagonal].

These crystals are tabular, consisting of a regular hexagonal prism terminated by basal planes.

With the polarizing microscope it gives a very perfect uniaxial figure of a positive sign. In this figure the yellow ring is the innermost, therefore $\rho < \nu$.

It being quite permanent in the air, no difficulty was experienced in making the above examinations. Hot or cold water immediately decomposes it. It is soluble in a solution of tartaric acid, and also readily soluble in dilute hydrochloric acid, from which it can be crystallized.

The antimony and chlorine were determined by precipitation, and the potassium was weighed as potassic chloride after ignition in a current of dry carbon dioxide gas. In this residue there was not a trace of any insoluble matter (absence of Sb_2O_3) after ignition.

Here, all the $SbCl_3$ was volatilized, giving again the data for the calculation of the percentage composition.

	Calculated for $SbCl_3$, 2 KCl.	Found.
Sb	31.95	30.44
Cl	47.20	47.21
K	20.85	22.34
	100.00	99.99

The loss of 1.51 % in antimony and the gain of 1.49 % in potassium were at first difficult to explain, but on taking into consideration the

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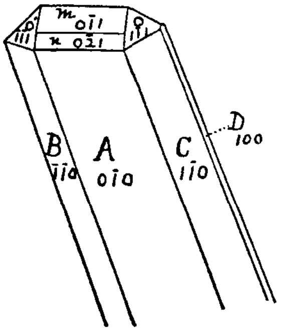
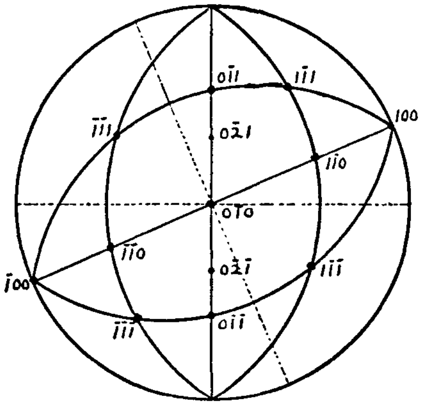
* Atomic weights used: — Sb 120; Cl 35.456; K 39.14; O 16.

fact that the per cent of chlorine in $SbCl_3$ is 47.04, in KCl is 47.53, and in this salt is 47.20, it is evident that an excess of potassic chloride would explain the discrepancy from the calculated results, and not materially interfere with the per cent of chlorine.

The crystals of this salt are, as has been stated, hexagonal plates. These plates pile up in layers, leaving the prism faces very much striated. This process of formation would tend to the occlusion of mother liquor rich in potassic chloride. As a matter of fact, a microscopical examination of the smallest, clearest, and most perfect crystals revealed numberless cavities with air bubbles and bubbles of liquid. This was the only salt in which such cavities and bubbles were found.

$SbCl_3 . 2\,KCl$ [Monoclinic].





$a : b : c = 1 : 1.381 : .9974.$

$\beta = 68° 57'.$

Angles between Normals.

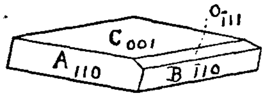
A B $0\bar{1}0 \wedge \bar{1}\bar{1}0 = 56° \; 6'$	A n $0\bar{1}0 \wedge 0\bar{2}1 = 36° \; 45'$
A C $0\bar{1}0 \wedge 1\bar{1}0 = 56° \; 0'$	A m $0\bar{1}0 \wedge 0\bar{1}1 = 56° \; 0'$
C D $1\bar{1}0 \wedge 100 = 34° \; 0'$	m m' $0\bar{1}1 \wedge 011 = 68° \; 0'$
C C′ $1\bar{1}0 \wedge 110 = 68° \; 3'$	C m $1\bar{1}0 \wedge 0\bar{1}1 = 56° \; 0'$
O′ O″ $\bar{1}\bar{1}1 \wedge \bar{1}11 = 61° \; 20'$	B O′ $\bar{1}\bar{1}0 \wedge \bar{1}\bar{1}1 = 46° \; 15'$

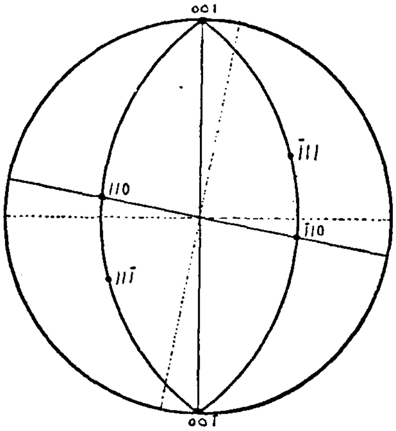
This salt is quite stable in the air. It is the dimorphous form of the previous salt.

	Calculated for $SbCl_3 . 2 KCl$.	Found.
Sb	31.95	32.13
Cl	47.20	47.20
K	20.85	20.70
	100.00	100.03

Here there is no great difference between the antimony and potassium percentages as before. Microscopic examination showed no cavities or bubbles of enclosed liquid.

$SbCl_3 . 2 KCl . 2 H_2O$ [Monoclinic].





$a : b : c = 1 : 1.3798 : .9358.$

$\beta = 78° 30'.$

Angles between Normals.

A B
$110 \wedge \bar{1}10 = 111° 40'$

A A′
$110 \wedge 1\bar{1}0 = 68° 48'$

A C
$110 \wedge 001 = 80° 35'$

A′ C
$1\bar{1}0 \wedge 001 = 80° 28'$

B C
$\bar{1}10 \wedge 001 = 99° 30'$

B′ C
$\bar{1}\bar{1}0 \wedge 001 = 99° 28'$

B B′
$\bar{1}10 \wedge \bar{1}\bar{1}0 = 68° 42'$

B O
$\bar{1}10 \wedge \bar{1}11 = 34° 31'$

O C
$\bar{1}11 \wedge 001 = 64° 57'$

The fact that this salt effloresced so readily at first prevented the making of any accurate crystallographic measurements. However, it was found that at a temperature of about —5° the salt retained its lustre for a sufficient length of time to afford very accurate measurements and crystallographic study. These crystals were of a tabular form, and upon looking through the plate with a polarizing microscope no interference figure could be discerned.

As the formula indicates, this is a hydrate of the two previous salts.

The water of crystallization is easily lost, even at a temperature of 15°. The weather at this period of the investigation was extremely cold, in consequence of which it was found that when the salt is kept in a room with the temperature at about —5°, it retains its water of crystallization for a period long enough to admit of weighing. The salt in the form of large isolated crystals was taken from the mother liquor, hastily dried between sheets of filter paper, crushed in a mortar, and finally rubbed between filter papers. Then it was transferred to a glass-stoppered weighing bottle, the whole operation occupying not more than 80 seconds at a temperature of —5°. From the weighing bottle it was quickly removed as desired; — the loss in weight of the bottle showing the amount of salt used. The determination of the water of crystallization presented several difficulties. Heating the salt in an air bath at 90°–95°, it will not come to constant weight in ten hours. If heated to 110°, it continues to lose in weight for a long time; in fact, there is a decomposition accompanied by the liberation of chlorine. Analysis of the salt heated to 95° showed that no Cl had gone off, but when heated to 110° there was a marked diminution of the percentage of chlorine, indicating a decomposition. At a temperature of 104° the salt will lose weight rapidly for a while, and then lose it *very* slowly for hours. Evidently the point where the last portion of water goes off and the point where the chlorine begins to be given off are nearly coincident. A great many determinations were made, and by estimating the chlorine every time the point could be very closely determined. Almost all the water will be given off in a desiccator over sulphuric acid, but it is a long time before the last trace is gone (thirty hours).

1. In a desiccator after 30 hours, the per cent of H_2O = 8.743
2. Heated in air bath 90–95°, at end of 4 hours = 8.476
3. " " 140° for 1 hour = 9.874
4. " " 105–107° for 5 hours = 10.24
5. " " 100–105° " " = 8.765

Nos. 1 and 5. The water has all been given off, and these are the two best values for the per cent of water. No. 2. The water is not all off yet, as shown by heating another hour, when per cent = 8.62. Nos. 3 and 4 both showed by analysis that chlorine had been evolved. The dried salts from Nos. 1 and 5 were used in the ignitions, and these gave results corresponding to the formula $SbCl_3 . 2\ KCl$. Calculating the percentages for the additional water of crystallization, the following result was obtained: —

	Calculated for $SbCl_3 . 2\ KCl . 2\ H_2O$.	Found.
Sb	29.16	29.07
Cl	43.07	43.07
K	19.02	18.53
H_2O	8.75	8.76
	100.00	99.43

In the ignited residue there was no insoluble portion of Sb_2O_3. The evidence warrants the selection of $SbCl_3 . 2\ KCl . 2\ H_2O$ as the formula for this salt.

The conditions under which these salts form are closely related. So much so that it has been difficult to establish the exact conditions under which each salt may be isolated. At first the work was wholly tentative, using a saturated solution of potassic chloride, and adding crystallized antimonious chloride, filtering off any insoluble portion. In this way were obtained the salts $SbCl_3 . SbOCl . 2\ KCl$, and $SbCl_3 . 2\ KCl$ (hexagonal). But in order more closely to study the relations of each to the others, a series of experiments was carried out in watch glasses.

To about 5 c. c. of a saturated solution of potassic chloride were added 5 grams of crystallized antimonious chloride; when this had all dissolved, as it will in the cold, more $SbCl_3$ was added, till the solution was so to speak saturated with $SbCl_3$. In all, about 30 grams of $SbCl_3$ were added. In each of a series of watch glasses was placed 1 c. c. of the above solution, and to the several glasses increasing amounts of a saturated solution of potassic chloride were added,— from 1 c. c. in the first to 5 c. c. in the last. In each a white precipitate was formed which redissolved on heating.

Then the reverse was tried, i. e. 2 c. c. $SbCl_3$, 1 c. c. KCl, down to 5 c. c. $SbCl_3$, 1 c. c. KCl. There was a precipitate in each watch glass, which however dissolved on heating. The watch glasses were placed on the window sill, with moderately cold weather, and examined at intervals.

Designating the salts by Roman numerals : —

$SbCl_3 . SbOCl . 2\,KCl$ . . . . I.
$SbCl_3 . 2\,KCl$ [hexagonal] . . . . II.
$SbCl_3 . 2\,KCl . 2\,H_2O$ . . . . III.

Contents of Watch Glass. Nov. 11, A. M.	Nov. 11, P. M.	Nov. 13, 8.30 A. M.	Nov. 13, 4 P. M. (Colder.)	Nov. 14, 6 P. M.
1 c.c. $SbCl_3$ sol. 1 c.c. KCl "	Monoclinic prisms. I.	Same. I.	Same. I.	Same. I.
1 c.c. $SbCl_3$ sol. 2 c.c. KCl "	I.	I.	General mass I., but the edges rounded off. A few II. Indications of III.	A few II. Two crystals of III.
1 c.c. $SbCl_3$ sol. 3 c.c. KCl "	I.	I.	I. a few remain. II. predominates. III. a good crystal.	Chiefly II. Several III. Remains of a few I.
1 c.c. $SbCl_3$ sol. 4 c.c. KCl "	I.	I.	Chiefly cubo-octahedrons of potassic chloride. II. present. I. but few remain.	Chiefly II. with amorphous KCl.
1 c.c. $SbCl_3$ sol. 5 c.c. KCl "	Clouds up. Possible indications of I.	Precipitate at bottom a few I. floating.	Chiefly cubo-octahedrons of KCl. No signs of I. A very few II.	Chiefly cubo-octahedrons with a few II.
2 c.c. $SbCl_3$ sol. 1 c.c. KCl " down to 5 c.c. $SbCl_3$ " 1 c.c. KCl "	— —	— —	Scum of white oxichloride. —	Same. —

During these experiments a number of mixtures of the two salts were crystallized in dishes under varying conditions.

Regarding salt I. ($SbCl_3 . SbOCl . 2\,KCl$), the evidence indicated that it crystallizes best from solutions by spontaneous evaporation in a cool place. Solutions should be preferably not too concentrated, and contain no large amount of free acid, i. e. no acid used in assisting the solution.

The hexagonal salt II. ($SbCl_3 . 2\,KCl$) results by evaporating either by heat or a vacuum desiccator a solution of almost any proportion of $SbCl_3$ and KCl with or without free acid; preferably concentrated solutions. This salt is the one most readily obtained of all the salts.

The hydrated salt III. ($SbCl_3 . 2 KCl . 2 H_2O$) crystallizes from moderately dilute solutions by exposure to severe cold, —10°. The presence of free hydrochloric acid does not interfere in any way, and possibly assists in the crystallization, provided it is not in too great an excess.

Lastly, *the monoclinic form of* $SbCl_3 . 2 KCl$. The hexagonal salt is readily obtained, and, if it is left in the mother liquor, after a few days undergoes a transformation from the hexagonal to the monoclinic. This is apparently accomplished by the building up of the hexagonal plates into a dumb-bell form, after which the planes of the monoclinic form are assumed, accompanied by an entire reconstruction of the crystal.

The mutual relations of these salts require further consideration. If a solution is made up as directed for preparing salt I. ($SbCl_3 . SbOCl . 2 KCl$), the addition of one drop of water beyond a certain point will cause a white precipitate, which is soluble upon heating, but which *reappears* on cooling. If, however, a crop of I. crystals is taken from the solution, and the mother liquor be divided in two portions, water can be added to one of them in considerable quantity, till finally one drop produces a cloudiness, which disappears on heating, but reappears on cooling. If now the second half of the mother liquor be added to the dish, the precipitate will not redissolve in the cold, but on heating it goes completely into solution, and is not thrown out on cooling. If this solution was left to evaporate after removing the crystals of I., there would soon be a deposit of II. ($SbCl_3 . 2 KCl$, hexagonal). But it is found that the addition of water as above described will promote the crystallization of more I. ($SbCl_3 . SbOCl . 2 KCl$).

When a solution depositing I. is placed at a temperature of —5° then III. will immediately be deposited.

When the salt I. is dissolved in hydrochloric acid just strong enough to effect the solution, there is deposited chiefly II., together with a few I.

When the salt II. is dissolved under the same conditions, there is dissociation, and the potassic chloride crystallizes out as cubes or cubo-octahedrons at first. Later, the salt will crystallize out itself as II.

As has been before stated, II. hexagonal goes into II. monoclinic on long standing at a moderate temperature. Considerable difficulty was experienced in attempting these crystallizations during rainy weather. The excessive moisture caused a white scum of oxichloride on every receptacle of the various solutions.

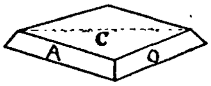
According to all analogy regarding the constitution of double salts, there would be three possible forms for the double chlorides of antimony and potassium; i. e. $SbCl_3 . KCl$; $SbCl_3 . 2\,KCl$; $SbCl_3 . 3\,KCl$. Singularly enough, as yet only the second one is obtained, and that is dimorphous. Solutions were made containing molecular proportions for $SbCl_3 . KCl$ and $SbCl_3 . 3\,KCl$. Each solution was divided into two parts, *one* of which was acidulated with hydrochloric acid, and the other not. The only resulting salts were:

1st solution, i. e. $SbCl_3 . KCl$ = I. and II.
2d " " $SbCl_3 . 3\,KCl$ = at first a lot of cubo-octahedrons of potassic chloride; later, II.

Although so many different forms were mentioned by previous writers, none such have been definitely proven in this research. Regarding the statement of Poggiale,* that the $SbCl_3 . 2\,KCl$ crystallizes in cubes, it may be mentioned that in the preparation of that salt a number of crystals appeared under the microscope as perfect cubes. But on isolating them and nursing them till they were of sufficient size to admit measurement, they were proven to be the hydrated salt III. ($SbCl_3 . 2\,KCl . 2\,H_2O$), with the angle not 90° but 80°. It is simply a different habit of the tabular crystal with no octahedral face. It may be possible that he observed the cubes of potassic chloride, which will crystallize from many of these solutions.

The mention of a triclinic crystal by Fehling* can be accounted for by the peculiar habit of this same salt III. of developing more rapidly on one side than another, giving to the eye a decidedly triclinic appearance. The trimetric form of Rammelsberg† may be explained in two ways.

First, the salt III. crystallizes often as per diagram, in which the plane of symmetry is through the dotted line, and O represents the octahedral face,‡ but the lower face is wanting where the crystal rests on the dish. At first sight this was taken for a trimetric crystal, but the angle of A ∧ C is different from that of O ∧ C, and no interference figure is seen with the polarizing microscope.



Secondly, the salt ($SbCl_3 . 2\,KCl$, monoclinic) crystallizes in diamond-shaped tablets, but the plane of symmetry is parallel to A, and octahedral faces are all wanting.* This occurs when there is a thin layer of mother liquor in the crystallizing dish. Obviously, this would be taken at first sight for trimetric, but measurement of angles and stauroscopic observations indisputably prove otherwise.

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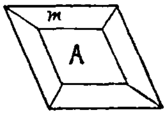
* This paper, page 213. † Ibid., page 214. ‡ Ibid., page 221.



No crystals were obtained crystallizing in any manner like leaves. In some cases there was obtained, when an exceedingly thin layer of liquid was allowed to evaporate, an arborescent formation as a thin coating on the bottom of the dish. This was $SbCl_3 . 2\,KCl$.

The salt Jacquelaine † described as in oblique rhombic prisms, with a formula $SbCl_3 . 2\,KCl$, may have been the salt described here as the monoclinic form of II., but it is rather singular that he made no mention of the hexagonal form which is the first to be obtained. On the other hand, it is quite possible that he meant the monoclinic salt, $SbCl_3 . SbOCl . 2\,KCl$, which is the first to crystallize from molecular solutions of $SbCl_3 . 2\,KCl$.

The writer is engaged in an investigation of the double salts of antimonious chloride with the bivalent metals.

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* This paper, page 220.

† Ibid., page 212.

X.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

CERTAIN BROMINE DERIVATIVES OF RESORCINE.

BY C. LORING JACKSON AND F. L. DUNLAP.

Presented February 14, 1894.

THE research described in the following paper was suggested by the observation* that tribromnitroresorcine diethylether, when heated with a solution of sodic ethylate, lost two atoms of bromine, which were replaced by two of hydrogen, so that $C_6Br_3NO_2(OC_2H_5)_2$ was converted into $C_6BrH_2NO_2(OC_2H_5)_2$. Considering the easy removal of these two atoms of bromine, it seemed possible that the tribromresorcine diethylether, which differs from it only in the absence of the nitro group, might behave in a similar way. This expectation has not been fulfilled, as our experiments have shown that tribromresorcine diethylether does not give up bromine to sodic ethylate at the boiling point of alcohol, and that the dibrom ether is not attacked below 200°, and therefore is, if anything, more stable than the symmetrical tribrombenzol, which according to Blau† is slowly converted into dibromanisol at temperatures of 120° to 130°. The behavior of free tribromresorcine was next studied, and it was found that bromine could be removed with great ease, even water at its boiling point decomposing this substance, while solutions of sodic carbonate, or sodic hydrate, or sodic ethylate dissolved in alcohol acted even more readily. These results show that the ethoxyl groups do not loosen the attachment of the bromine atoms to the benzol ring, whereas the hydroxyl groups have as much of this loosening effect as do the nitro groups in tribromdinitrobenzol.

We have not succeeded in determining the nature of the organic compounds produced by removing bromine from tribromresorcine, as they were brown amorphous bodies, which could not be brought into a state of undoubted purity for analysis. From their properties, however, it can be inferred that they are substituted resorcine ethers formed by a reaction involving the hydroxyl groups of the tribromresorcine. Sodium malonic ester gave a similar unmanageable product with tribromresorcine, but in addition to this acetylentetracarboxylic ester was isolated. This substance could hardly be formed here otherwise than by the action of brommalonic ester on sodium malonic ester, and the brommalonic ester must have been formed by the replacement by hydrogen of one or more atoms of bromine in the tribromresorcine. It follows, therefore, that in this respect also the two hydroxyl radicals behave like the two nitro groups in tribromdinitrobenzol, in which a similar replacement of bromine by hydrogen has been observed when this substance is treated with sodium malonic ester.

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* These Proceedings, XXVII. 315.

† Monatsh. f. Chem., VII. 630.

The tribromresorcine diethylether melts at 68°–69°, and is formed by the action of an excess of bromine on the dibromresorcine diethylether, melting point 99°–100°. This latter substance is prepared by the addition of bromine to a solution of resorcine diethylether in glacial acetic acid. The tribrom product was shown to have the bromine atoms in the symmetrical position to each other by treatment with nitric acid, which converted it into the tribromnitroresorcine diethylether melting at 101°, which is made from symmetrical tribromtrinitrobenzol.* The action of nitric acid on dibromresorcine diethylether was entirely different, as the product was a new dinitroresorcine diethylether melting at 126°, formed by the replacement of the two atoms of bromine by two nitro groups. A similar replacement of bromine by nitro groups was observed when the tribromresorcine was treated with fuming nitric acid, the product being the bromdinitroresorcine described by Typke† and Fèvre.‡ As this substance was obtained by the latter from dibromnitroresorcine, in this case also bromine was replaced by a nitro group, and several other cases are to be found in the chemical literature although they are far from common.

The most important point established by the observations given above is that in these cases hydroxyl or ethoxyl radicals have the same effect upon bromine which they have upon hydrogen attached to the benzol ring; for just as phenols are much more susceptible to the replacement of their hydrogen by halogens or nitro groups than the corresponding hydrocarbons, so the bromine can be replaced by other radicals, including the nitro group, much more easily in tribromresorcine than in tribrombenzol; while on the other hand the phenol ethers hold their hydrogen or bromine as firmly as the corresponding hydrocarbons. The one exception we have met with to this statement is the action of nitric acid upon dibromresorcine diethylether, in which the bromine is replaced by nitro groups, so that in this case the ether behaves like the free tribromresorcine rather than like the corresponding tribrom ether. This exception is the more remarkable, because we have found that toward other reagents, such as sodic ethylate, this dibrom ether shows the same great stability which characterizes the tribromresorcine diethylether.

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* These Proceedings, XXV. 183.

† Ber. d. ch. G., XVI. 555.

‡ Bull. Chem. Soc., XXXIX. 591.

As we could not remove the bromine from the tribromresorcine diethylether with sufficient ease, and the free tribromresorcine, although it gave up its bromine easily, gave unmanageable products since the hydroxyl groups took part in the reaction, we undertook the study of the tribromresorcine diacetate, which we hoped might give products that could be purified and analyzed; but these experiments did not lead to the desired result, as the acetate was converted into tribromresorcine by the reagents used, even boiling with water producing this effect to a slight extent, and consequently the products were those already mentioned as obtained from this substance. When treated with fuming nitric acid, the diacetate gives tribromnitroresorcine diacetate which melts at 161°.

The sodium salt of tribromresorcine was also studied. This was obtained in white crystals by precipitating an ethereal solution with alcoholic sodic ethylate, and seemed to contain two molecules of alcohol of crystallization. It was remarkable on account of its slight stability, as even *in vacuo* or in an atmosphere of hydrogen after standing for a short time it suddenly turned black, when there was a considerable evolution of heat and alcohol vapor was given off. The black residue gave up sodic bromide to water, and also a black soluble salt, while a red product was left behind. The black salt on the addition of acid gave a red precipitate similar to the product insoluble in water, but we were unable to bring either of these red amorphous substances into a condition undoubtedly fit for analysis; and although some analyses led to a very probable formula and reaction for the decomposition we can give no weight to these results, as we have no proof that the samples analyzed were homogeneous. There is no question that these substances are very similar to the products obtained from tribromresorcine and sodic ethylate or carbonate.

Dibromresorcine Diethylether, $C_6H_2Br_2(OC_2H_5)_2$.

Resorcine diethylether, prepared by Pukall's method,* was dissolved in glacial acetic acid and bromine added to it until no more was taken up and a yellow color appeared in the solution. Crystals were soon seen to separate, and these were recrystallized from alcohol until they showed a constant melting point, when they were dried in a desiccator and analyzed with the following results: —

I. 0.2262 gram substance gave, according to the method of Carius. 0.2644 gram of argentic bromide.

II. 0.2272 gram substance gave 0.2628 gram of argentic bromide.

	Calculated for $C_6H_2Br_2(OC_2H_5)_2$.	Found.	
		I.	II.
Bromine	49.38	49.74	49.22

Properties. — The dibromresorcine diethylether crystallizes in white silky felted long slender prisms terminated by one plane nearly at right angles to the sides; they melt at 99°–100°, and are slightly soluble in hot water; readily soluble in ether, benzol, and carbonic disulphide; very soluble in acetone and chloroform; also soluble in ligroin. Alcohol is the best solvent to use in purification.

In a sealed tube at 100° sodic ethylate does not react with dibromresorcine diethylether, nor was any action observed until the tube was heated to 200°, when, upon distillation of the product with steam, a few oil drops passed over. This experiment shows that the dibromresorcine diethylether is no more reactive than symmetrical tribrombenzol, if in fact as much so, since Blau has converted this latter substance, by heating it at 120°–130° with sodic methylate, into dibromphenol and its methylether.† As the interest in this work lay in the study of the effect of other radicals on the atoms of bromine rather than in the nature of the compounds formed, it was not thought worth while to spend the time necessary to prepare the product in quantity sufficient for its identification.

Dibromresorcine diethylether does not react with aniline in a sealed tube at temperatures ranging from 150° to 175°, and sodic phenolate at 230° also seems to have no effect upon it. It cannot therefore be called a very reactive substance.

Tribromresorcine Diethylether, $C_6HBr_3(OC_2H_5)_2$.

The crystals of dibromresorcine diethylether were treated with an excess of bromine, and then heated upon a steam bath until the excess of bromine had evaporated. The reddish oil which resulted soon solidified and was recrystallized from alcohol until it showed the constant melting point of 68°–69°, when it was dried in a desiccator and analyzed.

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* Ber. d. ch. G., XX. 1141.

† Monatsh. f. Chem., VII. 630.

0.2222 gram of the substance gave, by the method of Carius, 0.3177 gram of argentic bromide.

	Calculated for $C_6HBr_3(OC_2H_5)_2$.	Found.
Bromine	59.55	59.70

This body crystallizes beautifully in long pearly fibres, often collected in bunches and sometimes branched, which melt at 68°–69° and are practically insoluble in cold water; very soluble in benzol and carbonic disulphide; readily soluble in ligroin and chloroform; quite soluble in acetone, but less soluble in ether. Alcohol is the best solvent for purification.

This tribrom ether reacts but very slightly with sodic ethylate at the boiling temperature of alcohol, and no more strikingly when boiled with sodic amylate. When boiled with aniline, the tribrom ether gave an amorphous black mass from which nothing definite could be obtained. Inasmuch as the sodic ethylate had so little action on this body, it was deemed unnecessary to carry this line of work farther, for the reasons given under the dibrom compound.

Constitution of Tribromresorcine Diethylether.

Tribromresorcine diethylether dissolves readily in fuming nitric acid, giving the body $C_6Br_3NO_2(OC_2H_5)_2$, as was proved by its melting point, 100°–101°. As one of us and Warren * prepared this substance from symmetrical tribromtrinitrobenzol, this experiment proves the symmetrical position of the three bromine atoms in tribromresorcine diethylether.

Dinitroresorcine Diethylether, $C_6H_2(NO_2)_2(OC_2H_5)_2$.

When dibromresorcine diethylether is treated with fuming nitric acid, the result is different from that obtained with the corresponding tribrom compound. To study this action, some of the dibrom ether was added to an excess of fuming nitric acid, when it immediately dissolved, after which it was treated with excess of water and the reddish oil which separated allowed to solidify. It was then recrystallized from alcohol till it showed the constant melting point of 126°, after which it was dried at 100° and analyzed.

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* These Proceedings, XXV. 183.

0.1313 gram of the substance gave 13.5 c. c. of moist nitrogen at a temperature of 26° and a pressure of 746.6 mm.

	Calculated for $C_6(NO_2)_2H_2(OC_2H_5)_2$.	Found.
Nitrogen	10.94	11.19

Properties. — The dinitroresorcine diethylether crystallizes from alcohol in radiated clusters of long white needles, or of smaller curved needles forming woolly masses. It is of a very faint yellow color and melts when pure at 126°. It is readily soluble in chloroform and acetone; slightly soluble in ligroin; soluble in benzol; tolerably soluble in carbonic disulphide; soluble also in ether. Alcohol is the best solvent for purification.

Tribromresorcine, $C_6HBr_3(OH)_2$.

Tribromresorcine was prepared by the method of Benedikt,[*] as this yields better results than the treatment of resorcine dissolved in water with bromine, used by Hlasiwetz and Barth.[†] For this purpose the calculated amount of bromine is run into a solution of resorcine in cold glacial acetic acid. After the addition of the bromine this solution is somewhat warm, and upon cooling a finely crystallized product separates, which is best washed free from acetic acid by decantation. If more than the calculated amount of bromine is added, pentabromresorcine is formed in addition to the tribromresorcine. The yield by this method is slightly over 57 per cent of the theoretical.

A great many conflicting statements occur in the chemical literature regarding the melting point of tribromresorcine. Hlasiwetz and Barth, who discovered it, give no melting point. Typke,[‡] in some work on tribromdioxyazobenzol, obtained a body with a constant melting point of 104°. The amount of this body that he had was too small for analysis, but a careful comparison of its properties, especially its melting point, its crystalline form, and its solubility, with that of tribromresorcine he had prepared himself, convinced him of the identity of the two substances.

Rudolph Benedikt[§] by the action of tin and hydrochloric acid upon Stenhouse's pentabromresorcine, obtained tribromresorcine which melted at 111°. He also gives analyses which agree very well indeed for the body in question.

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[*] Monatsh. f. Chem., IV. 227.

[†] Ann. Chem., CXXX. 357.

[‡] Ber. d. ch. G., X. 1578.

[§] Ibid., XI. 2168.

Von Pechmann,* three years later, obtained a body by the action of an excess of bromine upon benzolresorcinephthaleïn, which he called tribromresorcine on the ground of the melting point of 103°. He gives no analysis of this body, notwithstanding the fact that Benedikt had previously found its melting point to be 111°.

Beilstein in his "Handbuch" gives only Typke's melting point of 104°.

All of the tribromresorcine we have made use of in this research melted at 111°, the point given by Benedikt, and repeated recrystallization from water, which seems to be preferable to all other solvents, failed to raise its melting point higher.

According to Hlasiwetz and Barth,† tribromresorcine when recrystallized from water contains water of crystallization, which it loses at 100°. As the presence of water of crystallization might explain the differences in the melting points given by previous observers, we examined the tribromresorcine in this direction. Some of it was crystallized from hot water and dried in the air to a constant weight. This air-dried salt, which remained constant in a desiccator over calcic chloride, was heated to 100° for ten hours, when 0.2169 gram of the substance lost but 0.4 milligram in weight. Therefore tribromresorcine when recrystallized from water does not contain water of crystallization which it loses at 100°, as Hlasiwetz and Barth state.

In the recrystallization of the tribromresorcine from hot water, especially from boiling water, it was noticed that the crystals had a light pink color, so a study of the action of boiling water upon this body was taken up. One gram of the pure tribromresorcine was boiled in a 500 c. c. flask, fitted with an inverted condenser, with 250 c. c. of water. The greater part of the solid went into solution, and after the boiling had proceeded but a very short time the liquid became pink in color, which deepened into a dark red after the action had been carried on for twenty-four hours. The portion of the tribromresorcine which did not go into solution melted under the boiling water, its color also changing from a pink to a very dark red after the boiling had been continued for some time. At the end of twenty-four hours' boiling, we found that all of the tribromresorcine had not been changed into the red body, for on cooling crystals of a light pink color separated from the solution, which had the melting point of

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* Ber. d. ch. G., XIV. 1061.

† Ann. Chem., CXXX. 357.

111°. Even further boiling, it seemed, failed to complete the change. Upon the addition of argentic nitrate to this solution, a heavy precipitate of argentic bromide was obtained, showing that bromine had been removed from the tribromresorcine.

The red body which formed the organic product in the reaction was amorphous, and could not be recrystallized from any solvents we could find.

It was thought that possibly in a sealed tube the reaction would run much more smoothly, converting all the tribromresorcine into the amorphous red body. Consequently, quite a number of experiments were tried with varying amounts of the substance, heated from twelve to twenty-five hours at different temperatures, but without success. The tribromresorcine, it seems, is incapable of complete transformation into the red body at temperatures below 200°, while at 200° it is carbonized after heating for a short time. As the solubilities of the red body are practically the same as those of tribromresorcine, all methods for purification failed, and it could not be brought into a state fit for analysis. It is probable, however, that it contains more hydroxyl groups than the tribromresorcine, forming perhaps in the first place a substituted pyrogallol, (for in alkaline solutions the red body immediately blackens,) which is afterwards converted into more complex substances by reactions in which the hydroxyls bear a part.

Aniline or sodic alcoholates also acted easily with the tribromresorcine, but although much bromine was evidently removed in the form of hydrobromic acid or sodic bromide, in no case could any organic product be isolated in a state fit for analysis.

Sodium Salt of Tribromresorcine, $C_6HBr_3(ONa)_2 . 2\ C_2H_5OH$.

This salt cannot be obtained from an aqueous solution, although it seemed to be formed, since upon treating tribromresorcine with a dilute solution of sodic carbonate carbonic dioxide was evolved, but the solution at once turned black and evidently underwent a deep-seated change. The following method for obtaining it was accordingly adopted. One gram of pure tribromresorcine was dissolved in absolute ether, and to this was added less than the calculated amount of sodium dissolved in absolute alcohol (the calculated amount of sodium is 0.13 gram). A precipitate immediately separated, consisting of short flat prisms having a silky lustre. These were filtered off and thoroughly washed with absolute ether. In the preparation of this body, the ether must be in large excess; if the reverse was true (that is, if the absolute alcohol were in excess) no precipitate was formed. The crystals were transferred, after washing with absolute ether, to a desiccator and allowed to dry in a stream of hydrogen. Some of the salt thus prepared was submitted to analysis. All the operations with this substance must be carried on as quickly as possible, since it has a strong tendency to decompose, forming a black mixture, and this change takes place even *in vacuo* or in an atmosphere of hydrogen, although not so quickly as when in contact with the air. Even during the weighing in a closed tube, the substance often decomposed, but the following analyses were made with the unchanged substance, although in all the analyses made the samples used were light brown in color, showing that slight decomposition had taken place.

I. 0.1357 gram of the salt gave 0.0396 gram sodic sulphate.
II. 0.1398 gram of the salt gave 0.0416 gram sodic sulphate.

	Calculated for	Found.	
	$C_6HBr_3(ONa)_2 . 2 C_2H_5OH$	I.	II.
Sodium	9.52	9.45	9.64

These results indicate that the salt contained two molecules of alcohol of crystallization, and that alcohol was present in the body was evident, for a great many times, in attempting to weigh it, the contents of the weighing tube would suddenly turn black, giving off heat, while a liquid collected in large drops on the sides of the tube which was recognized as alcohol.

Properties. — The sodium salt of tribromresorcine crystallizes in short flat prisms of a white color and a silky lustre. Its most striking property is its great instability, decomposing rapidly with the elimination of alcohol, the salt becoming black in color; when dissolved in water, the solution immediately turns black. A freshly prepared lot of this sodium salt was divided into two portions, one of which was put into a small tube through which a rapid stream of hydrogen was passing, the other was put into a test tube which was surrounded by a freezing mixture of salt and ice, the substance in the test tube being in contact with the air. It was found that the sodium salt in the stream of hydrogen (at ordinary temperature) blackened more rapidly than did the salt which was in the freezing mixture in contact with the air. This experiment proves that the salt is more stable in the cold than at ordinary temperatures, and also that the blackening is not due to oxidation. Since then we had proved that this behavior was not due to oxidation, it seemed possible that the black mixture obtained by drying at 100° might have the same percentage composition as the dried salt. Accordingly the amount of sodium was determined in a specimen of the salt which had been allowed to blacken and dried to a constant weight at 100°. The black body is slightly hygroscopic, so it must be weighed in a weighing tube.

0.2052 gram of the substance gave 0.0722 gram of sodic sulphate.

	Calculated for $C_6HBr_3(ONa)_2$.	Found.
Sodium	11.76	11.40

An attempt to determine the amount of alcohol present by heating some of the freshly prepared salt to 100° gave the following results: —

0.5944 gram of the substance lost at 100° 0.1068 gram in weight.

	Calculated for $C_6Br_3H(ONa)_2 . 2\,C_2H_5OH$.	Found.
Alcohol	19.05	17.97

This determination, although one per cent too low, is as near as we could expect it to come, inasmuch as it was impossible to obtain a sample for analysis which was perfectly white; but there is a more serious objection to this result and the determination of the sodium in the salt dried at 100°, as we have no proof that alcohol was the only substance volatilized during the decomposition and subsequent drying. In fact the determinations of the amount of sodic bromide contained in the dried mixture indicated that a certain quantity of hydrobromic acid might have been evolved. The only analyses of the salt, therefore, which are above suspicion, are those first given of the white undecomposed preparation.

The following experiments were tried to prove the nature of this decomposition of the salt. When the black decomposition product was dissolved in water, and dilute sulphuric acid added, a flocculent reddish brown precipitate was formed, which very much resembled ferric hydrate in appearance. The clear filtrate from this gave a very heavy precipitate of argentic bromide upon addition of argentic nitrate. This shows that the decomposition was produced by the elimination of a portion of the bromine from the ring. The amount of sodic bromide formed during the reaction was determined by treating the blackened salt with water of varying temperatures and for different lengths of time, and then the solutions were acidified with dilute sulphuric acid, the precipitate filtered off, and bromine determinations made in the clear filtrate. The results obtained were not constant, varying from 32.01 per cent to 37.90 per cent of bromine, and this variation may be explained by the supposition that a certain amount of hydrobromic acid escaped during the decomposition.

The study of the red flocculent precipitate obtained by the addition of sulphuric acid to an aqueous solution of the sodium salt of tribromresorcine has not led to any trustworthy results. Treatment with water and ether showed that it was not homogeneous, and the different fractions thus obtained could not be brought into a state fit for analysis, as no means of proving that they were pure could be found. Some of these analyses gave numbers agreeing fairly well with the very probable formula $[C_6H_2BrOH]_2O_2$; but for the reason just given it is impossible to accept this formula as established by them.

Tribromresorcine when treated with aqueous sodic carbonate dissolves with the evolution of carbonic dioxide, the solution immediately blackening, as has been stated already; upon acidification with dilute sulphuric acid a reddish brown flocculent precipitate was formed similar to that mentioned above, and the clear filtrate from this body gave a very heavy test for bromides. That in this case the blackening was not due to oxidation was shown by the fact that it took place in an atmosphere of hydrogen, even when the solution had been boiled to insure the absence of dissolved oxygen. Sodic or potassic hydrate has the same effect upon tribromresorcine as the carbonate. The red precipitate obtained upon acidifying has not yet been obtained in crystals, and when heated decomposed without melting, giving off hydrobromic acid. This body is doubtless the same as that obtained by the action of water on tribromresorcine, and also from the blackened sodium salt by acidifying its aqueous solution, as has been described above.

Action of Sodium Malonic Ester on Tribromresorcine.

This reaction was taken up to see if another case of the peculiar substitution of bromine by hydrogen, already noticed by one of us,* could not be obtained. After a great many trials the best mode for studying the reaction was found to be as follows. Five grams of sodium were dissolved in 250–300 c. c. of absolute alcohol, and to this were added thirty-five grams of malonic ester. Twenty-five grams of tribromresorcine were then added, and this turned dark and afterward dissolved. After boiling the mixture for three hours in a flask fitted with an inverted condenser, the alcohol was distilled off and the contents of the flask were acidified with dilute sulphuric acid. A dark red oil separated, which was dissolved in ether, this solution then dried over calcic chloride, and the ether distilled off. Upon standing several days, the residual oil turned rather viscous, and crystals were seen permeating the mass. These crystals may be obtained by absorbing the oil with bibulous paper or by distilling *in vacuo*. By crystallization from dilute alcohol the constant melting point 76° was obtained, and as the crystals are white, contain no bromine, and their solubility, mode of crystallization, and shape correspond with those of acetylentetracarboxylic ester, there can be no doubt that they are this substance. This acetylentetracarboxylic ester could hardly have been formed otherwise than by the action of brommalonic ester on sodiummalonic ester, and the brommalonic ester it would seem must have been produced by the interchange of a bromine atom of the tribromresorcine with one of the atoms of hydrogen of the malonic ester. It follows from this reasoning, therefore, that we have here another case of the curious replacement of bromine by hydrogen, so often observed in this Laboratory, and that the two hydroxyl groups of the resorcine exercise the same action on one or more of the atoms of bromine as the two nitro groups in the tribromdinitrobenzol. The following fruitless attempt was made to isolate the other organic derivative formed. If the red oil absorbed by the bibulous paper, after the acetylentetracarboxylic ester has been separated as completely as possible, be treated with benzol, it is divided into a soluble and an insoluble portion. The insoluble portion, by precipitating an alcoholic solution of it with benzol, came down in a flocculent form, and when dry was light brick-red in color. It was evidently closely related to the substance obtained by the action of water or sodic carbonate on the tribromresorcine, and like that could not be purified.

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* These Proceedings, XXIV. 1, 256.

Action of Nitric Acid on Tribromresorcine.

Fuming nitric acid reacts easily with tribromresorcine. The product was recrystallized from benzol and upon analysis gave the following results: —

0.2219 gram of the substance gave by the method of Carius 0.1479 gram of argentic bromide.

	Calculated for $C_6HBr(NO_2)_2(OH)_2$.	Found.
Bromine	28.67	28.37

This analysis and its melting point, 192°–193°, show it to be the body heretofore described by Typke * and Fèvre.†

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* Ber. d. ch. G., XVI. 555.

† Bull. Chem. Soc., XXXIX. 591.

We have found, in attempting to prepare the diacetate of dinitrobromresorcine, that dinitrobromresorcine would not react with acetyl chloride when heated with it at 100° for six hours in a sealed tube. Water does not react with dinitrobromresorcine in a sealed tube at temperatures varying from 100° to 150°. At temperatures between 150° and 190° the body is entirely decomposed, leaving a residue in the tube which seemed to be carbon, as it was insoluble in all solvents. It is strange that this substance should be less affected by water than the tribromresorcine, which is slowly acted on by water at its boiling point. The dinitrobromresorcine reacts with sodic ethylate, but, as in the case of the tribromresorcine, the resulting amorphous mass could not be purified or crystallized.

Behavior of Tribromresorcinediacetate.

While the tribromresorcine itself reacts readily with boiling water and sodic ethylate, but gives unmanageable products, and the di- and tribromresorcine diethyl ethers do not act with these reagents, it was thought that possibly the diacetate of tribromresorcine might be better to work with than either of the ethers or the free phenol, because it holds an intermediate place between the acid tribromresorcine and its neutral ethers. Instead of using Claassen's method* of boiling pentabromresorcine with acetic anhydride, then with glacial acetic acid, and finally with water, the tribromresorcinediacetate was directly prepared from tribromresorcine by treating it in a sealed tube for four or five hours at 100° with either acetyl chloride or acetic anhydride, preferably the former. It is best to use a slight excess of acetyl chloride, and after the heating is finished to decompose the excess by means of water. The diacetate is easily recrystallized from alcohol, and was identified by its melting point, 108°.

After boiling tribromresorcinediacetate with water for twenty-four hours, the water was slightly pink in color, and gave a feeble test for bromides with argentic nitrate. This is due, no doubt, to the fact that water at 100° saponifies a small part of the diacetate, yielding tribromresorcine, which in its turn is acted upon by the boiling water, as before noted. In the hope of avoiding this saponification, a sealed tube containing the diacetate was heated over night at 157° with ordinary acetic acid, but the saponification was not prevented, for the result was the same as if the free tribromresorcine had been heated with water alone to that temperature. Sodic ethylate in alcoholic solution when warmed with tribromresorcinediacetate deposited a precipitate which when filtered off soon turned black. This body was undoubtedly the decomposition product of the sodium salt of tribromresorcine. On account of the readiness, therefore, with which the diacetate was saponified, it was not worth while to carry on this line of investigation further.

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* Ber. d. ch. G., XI. 1439.

Tribromnitroresorcinediacetate, $C_6(NO_2)Br_3(OC_2H_3O)_2$.

The diacetate of tribromresorcine when added to an excess of fuming nitric acid immediately dissolved, and after standing several minutes the solution became very warm and began to boil, the body in solution becoming completely oxidized; but if just before the oxidation took place, when the solution was already hot, it was poured into an excess of water, the resulting yellowish oil soon solidified. The substance was purified by crystallization from alcohol until it showed the constant melting point of 161°, when it was dried at 100° and analyzed with the following results: —

0.1752 gram of the substance gave, by the method of Carius, 0.2086 gram of argentic bromide.

	Calculated for $C_6NO_2Br_3(OC_2H_3O)_2$.	Found.
Bromine	50.42	50.69

The diacetate therefore behaves toward nitric acid like the tribromether rather than like the tribromphenol itself, for in the latter and in the dibromether atoms of bromine are replaced by nitro groups, as already described earlier in this paper.

Properties. — The tribromnitroresorcinediacetate forms good-sized prisms terminated by two planes at an obtuse angle to each other: it is very pale yellow, almost white, and melts at 161°. It dissolves slowly in ligroin, is readily soluble in chloroform, benzol, and ether, quite soluble in acetone, and tolerably soluble in carbonic disulphide.

In order to establish if possible the position of the three bromine atoms in tribromresorcine, attempts were made to saponify the tribromresorcinediethylether, which has the three bromine atoms arranged symmetrically. When saponified in a sealed tube with aqueous hydrochloric acid, however, the product was a red body similar to that formed by the action of water on tribromresorcine. Accordingly, in hopes of a better result, dry hydrochloric acid gas was passed for one hour over tribromresorcinediethylether heated in an oil bath to 200°, but no saponification took place.

XI.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON MUCOPHENOXYCHLORIC ACID.

By Harris Eastman Sawyer.

Presented by H. B. Hill, February 14, 1894.

It was found some years ago, by Hill and O. R. Jackson,* that mucobromic acid was decomposed by treatment with baric hydrate, and that the course of the reaction varied, according as the solution was made strongly or feebly alkaline. In the first case, formic, dibromacrylic, and brompropiolic acids were formed. The product in the latter case, as has been shown in a more recent investigation,† was mucoxybromic acid. Hill and Stevens, pursuing the subject further, studied the action of potassic phenylate on mucobromic acid, and obtained a mucophenoxybromic acid whose constitution was established by its conversion into phenoxybromacrylic and phenoxybrommaleic acids.‡ They made, however, no attempt to prepare the corresponding series of chlorine compounds, because of the difficulties then attendant on the preparation of mucochloric acid. As it has become possible to obtain this acid in any desired quantity, it has seemed desirable to continue this work, which is now of more interest because of the relationship between the substituted mucobromic and mucochloric acids, and the recently described crotonolactones of Hill and Cornelison.§

The author would here express his deep obligations to Professor H. B. Hill, at whose suggestion the research was undertaken; and to Mr. Howard Nash, for assistance in some of the analytical work.

Mucophenoxychloric Acid.

The following method has been found most advantageous for the preparation of this acid. A solution of 17.6 grams of potassic hydrate and of 25 grams of crystallized phenol in 25 c. c. of water is cooled to 10°, and 13.2 grams of powdered mucochloric acid stirred in, as rapidly as is possible without rise of temperature. After standing for half or three quarters of an hour, at ordinary temperatures, the potassium salt of the new acid separates as a finely crystalline precipitate, which, after a second strong cooling, is filtered off and washed with a little ice-cold water.

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* These Proceedings, Vol. XVI. p. 188.

† These Proceedings, Vol. XXII. p. 316.

‡ These Proceedings, Vol. XIX. p. 262.

§ These Proceedings, *ante*, p. 42.

From a solution of this salt, hydrochloric acid precipitates mucophenoxychloric acid as an oil, which solidifies on standing, and may be recrystallized from benzol. From a solution of the pure potassium salt, however, the acid is precipitated at once, in the crystalline condition.

I. 0.1750 gram substance gave 0.3412 gram CO_2 and 0.0517 gram H_2O.
II. 0.2602 gram substance gave 0.1652 gram AgCl.
III. 0.3102 gram substance gave 0.1966 gram AgCl.

	Calculated for $C_4H_2(OC_6H_5)ClO_3$.	Found. I.	II.	III.
Carbon	52.98	53.17		
Hydrogen	3.09	3.28		
Chlorine	15.67		15.70	15.68

Mucophenoxychloric acid is sparingly soluble even in warm water, still less in cold. On the spontaneous evaporation of its aqueous solution, it crystallizes out in clusters of long, thin plates, melting at 91°. It is readily soluble in alcohol, ether, chloroform, and benzol, even in the cold, and is extremely soluble in hot benzol. It is dissolved but sparingly by carbonic disulphide and ligroin.

Potassic Mucophenoxychlorate, $KC_4H(OC_6H_5)ClO_3 . H_2O$.

An aqueous solution of the crude potassium salt, saturated at 50°, is filtered while warm, and cooled sharply in a freezing mixture. After some minutes, the salt separates in small rhombic plates which contain one molecule of crystal water. Thoroughly dried by pressure, these suffer no material loss of weight on exposure to the air; over sulphuric acid there is a diminution in weight corresponding to about one fifth of the molecule of water; at 95°, after a further loss approximately equivalent to the remainder of the molecule, browning and slight decomposition set in, making the exact determination of the crystal water impossible.

I. 0.3778 gram air-dried salt gave 0.1166 gram K_2SO_4.
II. 0.6117 gram air-dried salt gave 0.1878 gram K_2SO_4.
III. 0.3891 gram air-dried salt gave 0.1188 gram K_2SO_4.

	Calculated for $KC_4H(OC_6H_5)ClO_3 \cdot H_2O$.	Found. I.	II.	III
Potassium	13.84	13.89	13.79	13.71

Baric Mucophenoxychlorate, $Ba[C_4H(OC_6H_5)ClO_3]_2$.

It was first attempted to prepare this salt by neutralizing a cold aqueous solution of the acid with baric carbonate, and after filtration allowing it to evaporate *in vacuo* over sulphuric acid. This method, which gave satisfactory results with mucophenoxybromic acid,* proved fruitless here, for the solution rapidly became acid, and deposited crystals which, from their form and melting point, 91°, were evidently the free acid. The salt was finally prepared by precipitation of an aqueous solution of the pure potash salt, saturated at 50°, with a similarly saturated solution of baric chloride; on chilling in a freezing mixture, a crystalline precipitate appeared, which was sucked off, and washed with small quantities of ice-cold water, until the washings gave no precipitate with argentic nitrate. The salt crystallizes in small anhydrous rhombic plates, which are extremely soluble, even in the coldest water; and as its solution is so readily decomposed, no attempt was made to recrystallize it for analysis. When pressed dry between filter papers, it remained unchanged in the air, lost only a trifling amount of weight over sulphuric acid, and but a trifle more at 105°.

I. 0.2982 gram substance gave 0.1161 gram $BaSO_4$.
II. 0.2152 gram substance gave 0.0858 gram $BaSO_4$.

	Calculated for $Ba[C_4H(OC_6H_5)ClO_3]_2$.	Found. I.	II.
Barium	23.35	23.60	23.47

No detailed study has yet been made of the decomposition mentioned above; it has, however, been noticed that there is no formation of baric bromide, and that phenol and baric oxalate are set free.

Argentic Mucophenoxychlorate, $AgC_4H(OC_6H_5)ClO_3$.

This salt is best prepared by adding a solution of the potassium salt to an excess of moderately dilute argentic nitrate solution. There is an immediate precipitate of white granular crystals, which is increased in quantity by sharp cooling, and scratching. The salt is sparingly soluble in water, more readily in warm than cold, and is deposited by the warm concentrated solution in short compact prisms, which contain no crystal water.

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* These Proceedings, Vol. XIX. p. 264.

0.4115 gram substance gave 0.1771 gram AgCl.

	Calculated for $AgC_4H(OC_6H_5)ClO_3$.	Found.
Silver	32.40	32.40

A solution of this salt, on standing, undergoes a decomposition similar to that taking place in a solution of the barium salt.

PHENOXYCHLORACRYLIC ACID.

The reaction taking place when mucophenoxychloric acid is decomposed by an excess of alkaline hydrate, is analogous to that occurring when mucophenoxybromic acid is treated in like manner, the products being formic and a substituted acrylic acid.* Phenoxychloracrylic acid is most advantageously prepared in the following manner. Potassic mucophenoxychlorate is added to an equal weight of potassic hydrate dissolved in twice its weight of water, the mixture being gently heated on the water bath. On cooling, potassic phenoxychloracrylate separates in well formed crystals; these are dissolved in water and the acid is precipitated from their filtered solution by the addition of hydrochloric acid. When recrystallized from hot water, and dried over sulphuric acid, it gave the following results: —

I. 0.1862 gram substance gave on combustion 0.3738 gram CO_2, and 0.0616 gram H_2O.
II. 0.2362 gram substance gave 0.1702 gram AgCl.
III. 0.2018 gram substance gave 0.1458 gram AgCl.

	Calculated for	Found.		
	$C_3H_2(OC_6H_5)ClCO_2$.	I.	II.	III.
Carbon	54.41	54.75		
Hydrogen	3.51	3.68		
Chlorine	17.92		17.84	17.89

The acid dissolves readily in alcohol, ether, benzol, ligroin, and carbon disulphide; is nearly insoluble in cold water, and only sparingly soluble in boiling water, from which it may be crystallized in long silky needles, melting at 104°–105°.

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* These Proceedings, Vol. XIX. p. 267.

Potassic Phenoxychloracrylate, $KC_3H(OC_6H_5)ClO_2$.

When a hot aqueous solution of phenoxychloracrylic acid is neutralized with potassic carbonate, and partially evaporated, potassic phenoxychloracrylate separates from the concentrated solution in well formed plates, which may be recrystallized from hot water, although quite soluble in the cold.

These crystals are permanent in the air, and lose no weight at 110°. The air-dried salt was analyzed with the following results: —

I. 0.3310 gram ignited with H_2SO_4 gave 0.1206 gram K_2SO_4.
II. 0.1929 gram ignited with H_2SO_4 gave 0.0707 gram K_2SO_4.

	Calculated for $KC_3H(OC_6H_5)ClO_2$.	Found.	
		I.	II.
Potassium	16.49	16.34	16.43

Calcic Phenoxychloracrylate, $Ca[C_3H(OC_6H_5)ClO_2]_2 . 5\, H_2O$.

A hot aqueous solution of the acid is neutralized with calcic carbonate and concentrated, when the calcium salt crystallizes out in clusters of long needles, which are permanent in the air. They lose most of their crystal water over sulphuric acid, and the whole at 110°.

I. 0.7847 gram air-dried salt lost at 110° 0.1343 gram H_2O.
II. 0.3240 gram air-dried salt, ignited with H_2SO_4, gave 0.0847 gram $CaSO_4$.

	Calculated for $Ca[C_3H(OC_6H_5)ClO_2]_2 . 5\, H_2O$.	Found.	
		I.	II.
Water	17.14	17.12	
Calcium	7.62		7.69

0.1684 gram salt, dried at 110°, gave, on ignition with H_2SO_4, 0.0525 gram $CaSO_4$.

	Calculated for $Ca[C_3H(OC_6H_5)ClO_2]_2$.	Found
Calcium	9.19	9.17

Baric Phenoxychloracrylate, $Ba[C_3H(OC_6H_5)ClO_2]_2 . 5\, H_2O$.

The hot aqueous solution of the acid is neutralized with baric carbonate, evaporated until a thin film appears on the surface, and then allowed to cool, when the barium salt separates in clusters of long silky needles. These crystals appear to be slightly efflorescent, losing on exposure to the air for several days less than a molecule of water.

I. 0.3640 gram salt dried between filter papers gave, on ignition with H_2SO_4, 0.1346 gram $BaSO_4$.

II. 0.7799 gram salt dried between filter papers lost, at 110°, 0.1140 gram H_2O.

	Calculated for $Ba[C_3H(OC_6H_5)ClO_2]_2 . 5 H_2O$.	Found. I.	Found. II.
Water	14.47		14.60
Barium	21.52	21.64	

I. 0.1382 gram salt dried at 110° gave, on ignition with H_2SO_4, 0.6076 gram $BaSO_4$.

II. 0.1535 gram salt dried at 110° gave, on ignition with H_2SO_4, 0.6754 gram $BaSO_4$.

	Calculated for $Ba[C_3H(OC_6H_5)ClO_2]_2$.	Found. I.	Found. II.
Barium	25.75	25.85	25.87

Argentic Phenoxychloracrylate, $AgC_3H(OC_6H_5)ClO_2$.

On adding argentic nitrate to a hot aqueous solution of ammonic phenoxychloracrylate, there is precipitated crystalline argentic phenoxychloracrylate, which may be recrystallized from hot water in beautiful feathery needles. Dried over sulphuric acid it gave the following results: —

I. 0.1759 gram salt gave 0.0821 gram AgCl.

II. 0.1165 gram salt gave 0.0547 gram AgCl.

	Calculated for $AgC_3H(OC_6H_5)ClO_2$.	Found. I.	Found. II.
Silver	35.35	35.13	35.34

Phenoxychlormaleic Acid.

The structure of mucophenoxychloric acid has been further characterized by its oxidation to phenoxychlormaleic acid.

When a solution of mucophenoxychloric acid is heated with argentic oxide, there is deposition of metallic silver, and formation of argentic phenoxychlormaleate, which crystallizes from the hot filtered solution in minute stellate clusters. If the silver be precipitated with hydrochloric acid, and the filtered solution strongly concentrated, we obtain, on cooling, fine needles of phenoxychlormaleic acid. It has, however, been found advisable, on account of the sparing solubility of the silver salt, to prepare the acid in another way.

Hill and Cornelison found that mucophenoxybromic acid might advantageously be converted to phenoxybrommaleic acid by boiling the aqueous solution of its oxime;* and the same procedure has here been followed for the oxidation of mucophenoxychloric acid. Mucophenoxychloroxime is boiled with about twenty times its weight of water, until nothing separates on cooling. This solution is acidified with hydrochloric acid and extracted with ether, and the phenoxychlormaleic acid is removed from its ethereal solution by sodic carbonate, from which, in turn, it is separated by a second acidification and extraction; the ether is allowed to evaporate, and the crystalline residue is purified by sublimation in a current of carbonic dioxide. The anhydride thus obtained is dissolved in a small quantity of water, which, on spontaneous evaporation, deposits the acid as a mass of interlacing needles.

When thoroughly dried by pressure between filter papers, these crystals lose no weight in the air; but over sulphuric acid they suffer a gradual loss equivalent to one molecule of crystal water.

I. 0.2948 gram air-dried substance lost over H_2SO_4, 0.0195 gram H_2O.
II. 0.2769 gram air-dried substance gave on combustion 0.0860 gram H_2O and 0.4660 gram CO_2.
III. 0.1810 gram air-dried substance gave 0.0995 gram AgCl.

	Calculated for $C_4H_2(OC_6H_5)ClO_4 . H_2O$.	Found.		
		I.	II.	III.
Water	6.91	6.62		
Carbon	46.06		45.90	
Hydrogen	3.46		3.45	
Chlorine	13.62			13.60

0.1652 gram substance dried over H_2SO_4 gave 0.0960 gram AgCl.

	Calculated for $C_4H_2(OC_6H_5)ClO_4$.	Found.
Chlorine	14.64	14.38

The acid containing water of crystallization has no definite melting point, while that dried over sulphuric acid melts at 115°–122°, according to the mode of heating. It dissolves readily in water, alcohol, ether, chloroform, and benzol, is somewhat less soluble in ligroin, and only sparingly in carbonic disulphide. From hot benzol or ligroin it crystallizes in minute needles.

The identity of acids prepared by the two methods already described has been determined, in the absence of a definite melting point, by the identity of their anhydrides.

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* These Proceedings, *ante*, p. 53.

Phenoxychlormaleic Anhydride, $C_4(OC_6H_5)ClO_3$.

This substance, purified by sublimation, was analyzed with the following results: —

I. 0.2000 gram substance gave 0.0441 gram H_2O, and 0.3929 gram CO_2.

II. 0.1054 gram substance gave 0.0664 gram AgCl.

	Calculated for $C_4(OC_6H_5)ClO_3$.	Found.	
		I.	II.
Carbon	53.45	53.56	
Hydrogen	2.23	2.45	
Chlorine	15.81		15.60

It melts sharply at 97°, sublimes in thin curving plates, and dissolves readily in water, alcohol, ether, chloroform, and benzol, but only sparingly in ligroin and carbonic disulphide.

Baric Phenoxychlormaleate, $BaC_4(OC_6H_5)ClO_4 . 4 H_2O$.

This salt is most advantageously obtained in the following manner. Baric hydrate is added to a solution of the acid ammonium salt, prepared by boiling a solution of mucophenoxychloroxime, until the reaction is faintly alkaline. Baric bromide is then added in sufficient quantity to replace all the ammonium by barium, and on the addition of alcohol the new salt is precipitated in nodular aggregations of needles. It is filtered off, pressed dry, and redissolved in water, from which it is redeposited, on spontaneous evaporation, in bundles of long silky needles. When dried for analysis by pressure between filter papers, its weight remains constant in the air; but over sulphuric acid it suffers a loss corresponding to more than three molecules of crystal water, and at 110° there is a further loss, equivalent to the remainder of a fourth molecule.

I. 0.6161 gram air-dried salt lost over H_2SO_4, 0.0871 gram, and in addition at 110°, 0.0090 gram H_2O.

II. 0.1830 gram air-dried salt gave 0.0960 gram $BaSO_4$.

III. 0.1918 gram air-dried salt gave 0.1004 gram $BaSO_4$.

	Calculated for $BaC_4(OC_6H_5)ClO_4 . 4 H_2O$.	Found		
		I.	II.	III.
Water	16.02	15.60		
Barium	30.50		30.84	30.77

0.2060 gram salt, dry at 110°, gave 0.1273 gram $BaSO_4$.

	Calculated for $BaC_4(OC_6H_5)ClO_4$.	Found.
Barium	36.29	36.33

Argentic Phenoxychlormaleate, $Ag_2C_4(OC_6H_5)ClO_4$.

This salt was prepared by precipitating a solution of the acid with argentic nitrate, as well as by heating a solution of mucophenoxychloric acid with argentic oxide.

In both cases it crystallized in clusters of colorless and somewhat opaque dendritic needles, which were only sparingly soluble in hot water, and even less so in cold.

0.3590 gram air-dried salt gave 0.2252 gram AgCl.

	Calculated for $Ag_2C_4(OC_6H_5)ClO_4$.	Found.
Silver	47.29	47.22

XII.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

THE SMITHVILLE METEORIC IRON.

By Oliver Whipple Huntington, Ph. D.

Presented February 14, 1894.

In the early part of last summer Mr. Herman Meyer sold three new masses of meteoric iron from Smithville, De Kalb County, Tennessee, to Professor Ward, of Rochester, New York. After the largest mass had been sawed into slices these were kindly sent by Professor Ward to the writer for examination, and with it was sent the following letter describing the find: —

Smithville, De Kalb Co., Tennessee.

Three siderites, weighing about seven, fifteen, and sixty-five pounds each.

In November, 1892, Mr. John D. Whaley ploughed up the medium-sized meteorite. In a few days thereafter Mr. Berry Cantrell on the adjoining farm of James Beckwith ploughed up the large one at about two hundred feet distance from the first. These meteorites were carefully kept in the families of the respective finders. During December, after diligent search of some weeks, the third meteorite and the smallest was discovered and kept in the family of J. D. Whaley. On February 25, 1893, I obtained the medium-sized meteorite, and asked for thorough search of all their fields during the spring ploughing. This was done. Several pits were dug covering nearly the entire space of three hundred feet in all directions from the spots where the siderites had been found. The ground was looked over after each rain, and I myself looked over the ground well on two occasions, and no piece was found. Only after being sure the three pieces were all that fell did I announce the meteorites to the public, which I did, after purchasing the other two, on July 12.

The spot where found is three eighths of a mile south from Smithville and Lebanon Pike, two miles from Smithville, and on extreme southwest field of J. D. Whaley and adjoining field of James Beckwith. I satisfied myself that the meteorites were original and distinct, and that all was as represented. Since in my possession they have been strictly guarded.

Herman Meyer,
Cashier Bank of Carthage, Tennessee.

August 18, 1893.

This locality is about forty miles southeast from the spot on Cany Fork where the Carthage meteorite was found.

There is no question that the irons were found as stated in the above letter, but one familiar with the well known and widely distributed Cocke County iron could not but be struck with its close resemblance to the Smithville meteorites.

The largest mass of the Smithville iron, as shown in the plate, Figure 1, is roughly spherical, with no signs of original crust, but marked by one deep pitting which once contained troilite now nearly weathered away, or possibly melted out during the flight of the body through the atmosphere. That the specimen had lain for a long time in the soil is evident from its being coated with a thick covering of magnetic oxide of iron, the magnetism being strong enough to attract iron nails with considerable force. This covering, however, does not fully conceal certain very typical features of the iron,— a marked silvery whiteness, a very striking and ready octahedral cleavage, a slightly yellowish metallic foil separating the crystalline plates of iron, — also numerous nodules of a very cleavable troilite, embedded in graphite and granular schreiberseit; while perhaps the most striking feature of all is a nodule of fine-grained compact graphite nearly two inches in diameter. This is probably a larger mass of meteoric graphite than any on record. The only one which compares with it is that formerly described by J. Lawrence Smith in the Sevier County iron.* The weight of the Smithville nodule cannot be accurately estimated, as it was not observed till the mass had been sawed into slabs. It appeared to be nearly spherical, with a diameter as great as the longest dimension of the dumb-bell shaped nodule described by J. Lawrence Smith, making the total mass of the former considerably greater than that of the latter.

Figure 2 of the plate represents an etched surface of the largest section of the sixty-four and a half pound specimen of the Smithville iron, and here again are very striking features. The natural size of the section is nine and a quarter inches by seven. Near the lower right-hand corner can be seen, somewhat indistinctly outlined, the large nodule of graphite just described, while the rest of the plate brings out quite markedly the peculiar features of the Widmanstättian figures. In the first place, nodules of graphite and troilite are abundantly scattered over the surface. Usually these nodules are troilite embedded in graphite, and this in its turn is surrounded by schreiberseit, though there is considerable variety in the relative arrangement of these three minerals in the individual nodules. In places the schreiberseit widens out into bright patches between the Widmanstättian plates, especially in proximity to the troilite nodules.

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* American Journal of Science, 3d ser., Vol. XI. p. 392, 1876.

This inequality in the distribution of the schreiberseit gives a very varied appearance to the etched surface, and areas selected from opposite ends of the slab shown in the plate (Fig. 2) could not possibly be identified by the Widmanstättian figures alone. In this character the iron very closely resembles those of Arva and Sarepta.

Several analyses were made of the Smithville iron, though in the opinion of the writer such analyses are of very little value on account of the difficulty of sampling, since the nickel and cobalt must vary with the tænite plates, while the phosphorus would depend upon how much schreiberseit happened to be in the mixture selected for analysis. Choosing, however, as uniform material as possible, the average analysis gave: —

Iron	91.57
Nickel	7.02
Cobalt	.62
Copper	Trace
Phosphorus	.18
Residue, mainly Cliftonite	.15
	99.54

Comparing this with the irons most closely resembling it we have: —

	Greenbrier Co.,* West Virginia.	Jennie's Creek,† Wayne Co., W. Va.	Cosby's Creek,‡ Cocke Co., Tenn.	Sevier Co.,§ Tenn.	
Iron	91.59	91.56	87.00	93.80	94.03
Nickel	7.11	‖ 8.31	‖ 12.00	4.66	4.44
Cobalt	.60				
Copper	Trace				
Phosphorus	.08	.13			
Carbon	—	—	.50		
Residue	.12				
Loss	—	—	.50	.10	.10
	99.50	100.00	100.00	98.56	98.57

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* Mineralogical Magazine, Vol. VII. p. 183, 1887.

† American Journal of Science, 3d ser., Vol. XXXI. p. 145, 1886.

‡ Ibid., 1st ser., Vol. XXXVIII. p. 250, 1840; Ibid., 1st ser, Vol. XLIII. p. 354, 1842.

§ Ibid., 2d ser., Vol. IV. p. 83, 1847.

‖ By difference.

No analyses have been made of the meteorites of Waldron's Ridge,* Claiborne Co., and Lebanon,† Wilson Co., Tennessee, but they are generally accepted as identical with the Cocke County iron.

Of the above analyses the Greenbrier County is probably the most reliable, and this it will be seen is almost identical with the Smithville. The analysis of Jennie's Creek is of very little account, since it consists of a determination of the percentage of the iron alone, the balance in weight being set down as nickel and cobalt, while the analyses of the Cocke County and Sevier County, unquestionably the same iron, differ widely from each other.

In marked contrast to this variation is a collection of analyses placed in comparison by Fletcher, when describing the Greenbrier County specimen now in the British Museum.‡

	Greenbrier Co.	Trenton. (L. Smith.)	Rio Juncal. (Damour.)	Seneca River. (Shepard.)	Staunton. (Santos.)
Iron	91.59	91.03	92.03	92.12	91.44
Nickel	7.11	7.20	7.00	7.54	7.56
Cobalt	0.60	0.53	0.62		0.61
Copper	Trace	Trace			0.02
Phosphorus	0.08	0.14	0.21	0.08	0.07
Sulphur	Trace				0.02
Residue	0.12	0.45		0.26	0.14
	99.50	99.35	99.86	100.00	99.86

On glancing at the above table one would suppose that it exhibited parallel analyses of the same iron, whereas they are actually irons so widely separated by their physical characters as well as by their geographical distribution that in our present knowledge of the subject we are forced to regard the resemblance of the chemical analyses as an accidental coincidence.

Although a mere chemical analysis seemed insufficient to identify the Smithville iron with the Cocke County, or Sevier County iron, one point in its composition seemed important. After dissolving a portion of the Smithville iron in hydrochloric acid, assisted by a battery,[*] a black residue was obtained, consisting mainly of small graphitic crystals, with a predominence of cubo-octahedral forms, but showing also perfect little cubes without any modifications, and others with their edges truncated by the dodecahedron, and occasionally bevelled by a very obtuse tetrakis hexahedron. This was evidently the now well known form of meteoric graphite, first seen by Haidinger in the Arva iron,[†] named Cliftonite by Fletcher in the Youndegin iron,[‡] but also found by him in the Cocke County iron.

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* American Journal of Science, 3d ser., Vol. XXXIV. p. 475, 1887.

† Ibid., Vol. XXXIII. p. 118, 1887.

‡ Mineralogical Magazine, Vol. VII. p. 183, 1887.

While examining a nodule of graphite formerly obtained by J. Lawrence Smith from the Sevier County iron, it was accidentally broken and showed in its interior what appeared to be a skeleton octahedron of graphite three eighths of an inch in diameter, and with all but one of its faces sufficiently perfect for measurement by an application goniometer. This striking feature at once suggests that this also may be a pseudomorph after diamond.

With the Cliftonite from the Smithville iron were to be seen numerous white glassy grains. On digesting the residue for a long time with hydrofluoric acid, most of the white grains disappeared, but a few remained entirely unaffected by the acid. These appeared as very brilliant transparent angular fragments, and exhibited a hardness sufficient to scratch the ruby. As only a few grains were obtained from the amount of iron placed at the disposal of the writer, no further experiments could be made, but in all probability the grains were diamond.

In a letter from Professor Ward dated October 13, 1893, he says, "The 'Smithville' seems to cut harder than any iron which we have yet undertaken"; and Fletcher says of the Youndegin iron, "The large specimen was cut on the premises of the Museum by means of hack-saws, and was found to be so hard that three weeks were required for the severance of a fragment of which the cut face is not two and a half inches square."[§] May not this unusual hardness be accounted for by the presence of minute diamonds?

In view of the constant occurrence of graphite in meteoric iron, and the frequent appearance of the same in the crystalline form of diamond, (the carbonaceous material apparently varying in hardness from one and a half on the usual scale to the maximum hardness in the crystals of true diamond as found by the writer in the Cañon Diablo iron,*) may it not be that all meteoric iron contains diamonds at least of the carbonado variety, only waiting for a sufficiently careful search to reveal them, and that the peculiar toughness of these irons, so imperfectly accounted for by the network of Widmanstättian plates, may be explained by the presence of the hardest substance known in a state of excessively fine division?

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[*] These Proceedings, Vol. XXIX. p. 204.

[†] Pogg. Annalen, Bd. LXVII. p. 437, 1846.

[‡] Mineralogical Magazine, Vol. VII. p. 121, 1887.

[§] Ibid., p. 123.

Glancing now for a moment at the accounts of the several masses of the Cocke County iron, we can see why this same iron has kept coming to light year after year ever since 1840. That it is given a different name each time is not to be wondered at, since the prices paid for meteorites by collectors puts a great premium on names.

In the first description of the Cocke County iron, in 1840, Dr. Troost says at the opening of his paper: "During my excursions through East Tennessee I had seen small fragments of native iron, and had heard of large masses of it. It being considered a precious metal, all that was known about it, and the place where it was found, were kept a profound secret." †

He then goes on to state how a few small pieces had come into his hands, and that he believed the original mass weighed two thousand pounds. He also adds that he went to Buncombe County, North Carolina, where there was said to be a great quantity of it, but found none.

Two years later Professor C. U. Shepard described a mass in the museum of the East Tennessee University at Knoxville, and quoted a letter in regard to it: —

"It is a portion of an irregular mass, which was given me about five years since. The mass, as you have been informed, was discovered in Cocke County. The proprietor resisted for some time all importunities to discover where it was; believing it to be some metal of great value. I assured his agent that it was native iron, and probably meteoric. After he became satisfied of its character, many individuals examined it, in place. It was entirely insulated on the ground, and weighed about seven or eight hundred pounds. Specimens were obtained from it and dispersed through the country.

"It was my intention to have purchased and transported the entire mass to Knoxville, until I learned that Dr. Troost, Geologist of the State, had obtained the refusal of it. He has conveyed it since to Nashville." *

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* These Proceedings, Vol. XXIX. p. 204.

† American Journal of Science, 1st ser., Vol. XXXVIII. p. 250.

Later on, Shepard quotes two letters describing the original Cocke County mass: "The large mass of meteoric iron found some years ago in Cocke County (on a creek called Cosby's) fell into the hands of some persons who tried to break it with sledge-hammers; but not succeeding, they placed it upon what is here called a 'log-heap,' where, after roasting for some time, it developed certain natural joints, of which advantage was taken with cold chisels and spikes for its separation into fragments. These were put into a mountain wagon, and transported thirty or forty miles to a sort of forge, and there hammered into 'gun-scalps,'† and other articles of more common use. Some remnants of the mass fell into the hands of Dr. Troost. The original mass was one of rare character, and ought to have been preserved entire. Much of it was composed of large and perfect octahedral crystals. Its weight was about a ton. Another mass weighing one hundred and twelve pounds was found near the locality of the larger one. This also was malleable, very white, and easily cut with a sharp instrument. It was picked up by a mountaineer, who, supposing it to be silver, asked fifteen hundred dollars for it. After retaining it for some years, he finally sold it to a friend of mine for a small sum, who transferred it to Dr. Troost."

Second letter: "The weight of the mass has been variously estimated; but I am certain it was never weighed prior to its being broken up. It was probably about two thousand pounds. In figure, it was an oblong square block. I saw several very regular octahedral crystals which had been detached from the exterior angles of the mass. I had formerly supposed that the whole of it had been taken to Lary's forge, in Sevier County, and the greater part of it there wrought into 'gun-scalps'; but very recently I have been informed that part of it was taken to the forge of Peter Brown, in Green County, and there forged. I understand that a man by the name of McCoy had a neat bar forged from it for making a gun-barrel, which, to use the expression of Brown's son, "was as bright as silver." In conversation young Brown informed me that he thought a piece of the iron in its natural state still remained. On searching, it was found by a little girl of the

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* American Journal of Science, 1st ser., Vol. XLIII. p. 354, 1842.

† The forged iron bar before being bored for a gun barrel is called in Tennessee a "gun-scalp."

family. It weighs rather more than a pound, and had been preserved by the family as a nut-cracker." *

About the year 1880, a fragment of iron, said to weigh eleven pounds, was found in Greenbrier County, West Virginia, in regard to which Fletcher says: "The finder and his official agent, thinking it a piece of rich iron ore, searched unsuccessfully for a vein: the specimen itself was taken to a country smith's shop, heated, and cut with a cold chisel; the fragments were distributed as specimens of iron ore. Some time afterwards, two of them, weighing respectively 63 oz. and 31 oz., were given by the agent to Mr. Matthew A. Miller, Civil Engineer, of Richmond, Virginia; convinced of their meteoric origin, he immediately tried to recover the pieces already distributed, but after travelling several hundred miles was forced to the conclusion that they were irrecoverably lost." †

Later still Mr. George F. Kunz describes three small pieces from Wayne County, West Virginia, the largest of the three only weighing a little over half a pound, the rest of the original mass having been broken up and distributed.‡ The Wayne County specimens were sent to the writer by Mr. Kunz before being described, and were identified at once as more of the Cocke County iron. In connection with this iron a supposed fall of a meteorite in the direction of Wayne County some five years previous was quoted, but any one familiar with meteorites knows how frequently such accounts have to be rejected, even when the observer thinks the specimen fell at his feet, and that he picked it up while still too hot to hold.

Another piece of the Cocke County iron was given to Professor N. S. Shaler in 1887, purporting to be a sample of a vein of native iron of indefinite extent, near Lebanon, Wilson County, Tennessee. It may be that this fragment was originally broken off from the Smithville irons and that they were the iron vein referred to, since they were found not far from the Lebanon Turnpike, though in the adjacent county.

The map on the opposite page, drawn to scale, will give an idea of the distribution of the counties in which the various irons under discussion were found.

At first one might be led to suppose that these numerous masses of iron resulted from a wide-spread shower, but on looking over the

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* American Journal of Science, 2d ser., Vol. IV. p. 84, 1847.

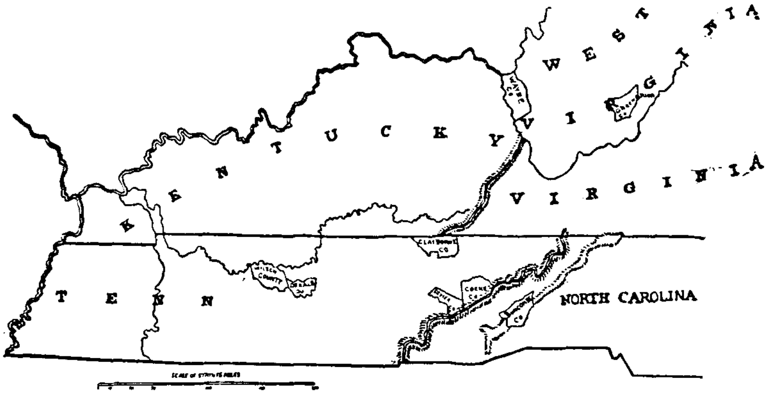
† Mineralogical Magazine, Vol. VII. p. 183, 1887.

‡ American Journal, 3d ser., Vol. XXXI. p. 146, 1886.

records it is obvious that portions of the original mass from Cocke County were distributed far and wide; and since only small portions have found their way into museums, it is not surprising that they have been turning up so frequently.

Thus we have: —

	Reported Weight.	Collected.
Cocke County	2,000 lbs.	A few small pieces.
Sevier County	112 "	112 lbs.
Wayne County	27 "	2 "
Greenbrier County	11 "	Less than 6 "
Wilson County	1½ "	1½ "
Waldron's Ridge, Tazewell County	18 "	18 "



Thus we see that about a ton of this iron is still missing, and, though some of it has been used up at a blacksmith's forge, other pieces are known to have been deliberately buried and dug up again to sell as samples of iron or silver mines, while others still have been carried to long distances, treasured by the owners as silver or some other metal of value, and this has been going on for more than fifty years.

At this late date, therefore, it is impossible to form any conclusion in regard to the original distribution of the irons under discussion, or to determine whether only one mass originally fell, or whether there was a large shower, spreading over a considerable area, as in the case of the Cañon Diablo meteorite recently studied.

That in several cases specimens in our cabinets under different names came from this original Cocke County mass is more than probable, but it may well be that in other cases the identity of characters only indicates that the several masses were parts of the same meteoric shower. The multiplication of unnecessary names is unfortunate, and for the simplicity of our catalogue it is desirable that such questions as the present should be investigated.

In conclusion, the writer wishes to thank Professor H. A. Ward, of Rochester, New York, for his kindness in having the plates made with which this paper is illustrated, and for his extreme courtesy in furnishing material for analysis, as well as sending for inspection the large mass sawed into slabs.

XIII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XLII. — ON AN APPARATUS FOR THE MEASUREMENT OF COEFFICIENTS OF SELF-INDUCTION, AND THE INVESTIGATION OF THE PHENOMENA OF ALTERNATING CURRENTS.

By Frank A. Laws.

Presented by Charles R. Cross, January 10, 1894.

The increasing use of alternating currents in telephony and electric lighting has, during the last few years, directed attention to the measurement of coefficients of self-induction. In this paper certain apparatus devised for this purpose, together with methods for its use, will be described. Further discussion of the various methods of measurement proposed and of experimental results obtained is reserved for a later article.

For investigations pertaining to telephony it is particularly desirable to measure inductances by means of alternating currents of suitable known frequencies, and of the same order of magnitude as those used in practice. In all such work the reduction of the results is greatly simplified if the E. M. F. employed follows the sinusoidal law. Therefore the aim at the outset was to produce a dynamo whose E. M. F. should vary in this manner, and whose frequency of alternation should be about that which is normal in telephonic work. Under these requirements there have been designed in the Rogers Laboratory two dynamos, or arrangements of dynamos. The first of these was planned during the winter 1890–91, and was used by Mr. L. Derr in connection with his thesis in 1891–92. This machine was provided with a stationary armature having Lord Kelvin's zigzag winding on the outer surface of a hollow cylinder. This was placed in the gap between a star-shaped piece of iron and a disk with a corresponding star-shaped opening, the two pieces being similarly and concentrically placed and forming the pole pieces of the machine. Owing to the shape of the pole pieces the field between them is variable, being denser at the points of the stars, so that when the field moves past the armature an E. M. F. will be set up in the latter.

One disadvantage of this design is that the E. M. F. is small, owing to the very large non-effective field; for it is only the variation of the field that is of service in producing the E. M. F. By properly shaping the pole pieces a curve of E. M. F. was obtained, which, when plotted, was found to be nearly sinusoidal in form.

The second machine was constructed by Messrs. C. L. Norton and P. H. Thomas, of the class of 1893, and forms the subject of the present paper. The special form of dynamo used was designed in accordance with a suggestion from them. The frequency is somewhat low, being 400 complete alternations per second. When another machine is built, it will be so designed that the superior limit will be raised to 2,000 complete periods per second.

Both the machine of 1890 and that of 1892 embody the same general features. Each has two independent armatures, one fixed, the other movable in phase relation to the first. This relation is capable of measurement. At the outset it was determined that in these machines the armatures should contain no iron, and that they should remain stationary, in order to eliminate any possible microphonic action at the brushes.

The machine, which is shown in place ready for use in Figure 1, will now be described. It consists, in brief, of two dynamos, with revolving fields mounted on one shaft to insure definite phase relation. The armature of one is fixed, while that of the other may be given any desired angular advance or retardation in reference to the first by means of a tangent screw. This advance can be read off from the graduated head of the screw. The fields are independent of one another. In addition to the dynamos the shaft carries a contact arrangement for mapping wave-forms, and a stroboscopic disk for determining the speed of rotation.

One of the field magnets is shown in plan in Figure 3 and in section in Figure 2. It consists of two star-shaped pieces of cast iron, keyed to the shaft and having hubs of such a length that the faces of the teeth are $\frac{5}{16}''$ apart, thus leaving a gap in which is the armature, $\frac{1}{4}''$ thick. The castings are recessed to receive the field coils, which are about one square inch in section and contain 250 turns of No. 16 B. & S. double cotton-covered wire. The coils were wound on forms, paraffined and taped, and were inserted when the machine was assembled. The terminals are brought out through bushed holes and fastened to composition collector rings, which are carried and insulated by blocks of vulcanite mounted on the tips of the teeth of one of the castings. The brushes of spring copper are supported from the base plate. The eight teeth were milled from the round by a special Brown and Sharpe cutter, and have the form of a sinusoid laid off radially from the base circle. Of course, owing to the spreading of the lines of force, the particular form to be given to the teeth in order to obtain the best action can only be ascertained by trial.

The armature consists of a vulcanite disk, 10¼″ diameter, ¼″ thick, having a 4″ hole in the middle. From this hole radiate sixteen equally spaced saw-cuts $\frac{3}{16}$″ deep, $\frac{1}{16}$″ wide, and 2¼″ long, the outer extremities of alternate pairs of cuts being connected by grooves concentric with the disk. In these cuts and grooves the armature wires are laid in shellac. The windings at present consist of three sections having respectively 10, 10, and 20 turns of No. 30 B. & S. copper wire. The total resistance is about ten ohms. The manner of winding as well as the action of the dynamo, by varying the length of active wire, are evident from Figure 3. The armatures are carried by built up hard-wood rings, 10¼″ outside diameter, 8¼″ inside, and 1$\frac{9}{16}$″ deep. The ring in one dynamo is attached to a brass disk and hub, which fit the shaft and are rigidly bolted to the frame of the machine.

In the other dynamo, the armature, ring, disk, and hub are attached to a worm-wheel, and the whole is movable on a sleeve supported firmly from the frame of the machine. Through this sleeve passes the shaft without contact. The worm-wheel gears into a tangent screw provided with a divided head, the gearing being such that 1° on the wave form is represented by 20° on the head. Backlash is prevented by a spiral spring. See Figures 2 and 3.

Between the two dynamos is a brass disk, keyed to the shaft and provided with an insulated collector ring and contact point. By the side of this disk is a radial arm, revolving freely about the shaft, and capable of being clamped at any desired point to a fixed graduated circle. The arm carries the contact spring, made of watch spring and supported on its lower side very near its extremity to prevent the lengthening of the arc of contact by vibration. The spring can be moved out of contact with the point by a fine-pitched screw. This contact arrangement we have found to work satisfactorily at as many as 3,000 revolutions per minute.

The shaft of the machine is of steel, 1″ in diameter, 29″ long, and runs in composition bearings, each of which is 5½″ long. The frame of the machine is heavy, weighing 175 pounds, and is designed so as to be very rigid. Driving is effected by means of a 2″ belt running over a 5″ pulley. The motor (1 H. P.) is of the Sprague type.

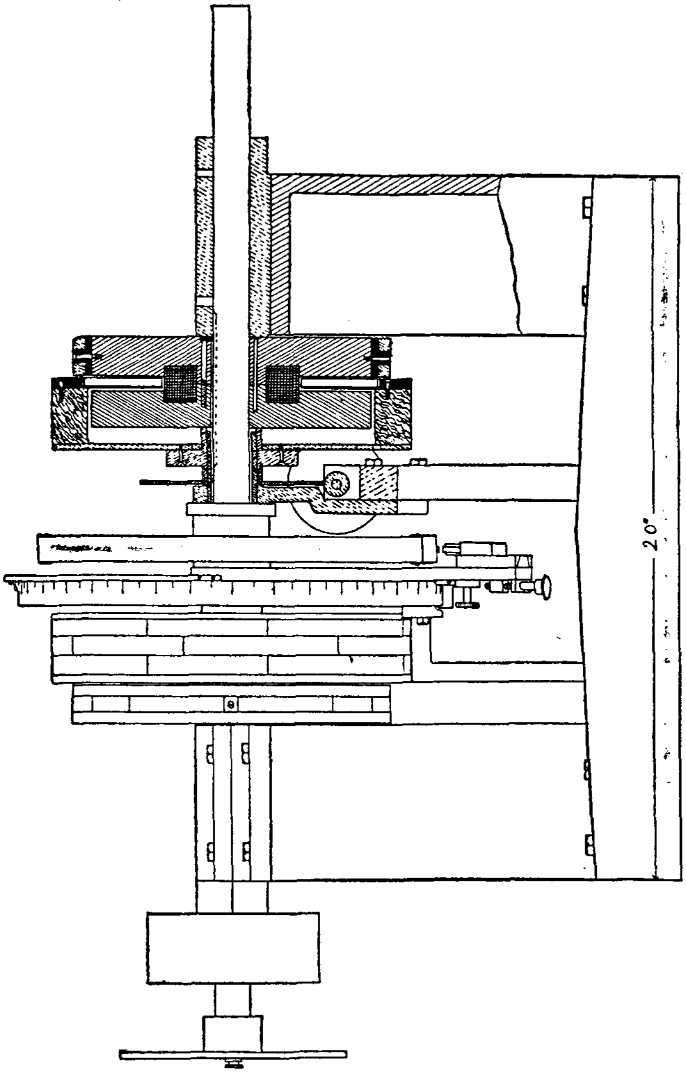


Fig 2 Elevation and Half Section through Dynamo A

Variations of speed are obtained by the use of pulleys of different sizes on the motor shaft.

Both machine and motor rest on a brick pier, the machine being set in sulphur; mechanically, the arrangement leaves nothing to be desired. It has been run continuously at the rate of 3,000 revolutions per minute, without perceptible jarring.

The machine was at first supplied with a mechanical counter, which could be thrown on or off by means of an electro-magnet operated by a key. We found, however, that the arrangement was unsatisfactory, as variations of speed were introduced by its friction and inertia. Moreover, such an arrangement gives only the average speed during a given time; we therefore abandoned this counter, and adopted a stroboscopic device. A ray of light is reflected upon the revolving segmented disk from a mirror attached to an electrically driven tuning-fork of known rate. With such an arrangement the desired speed may be attained, and variations from it measured by noting the apparent motion of the disk.

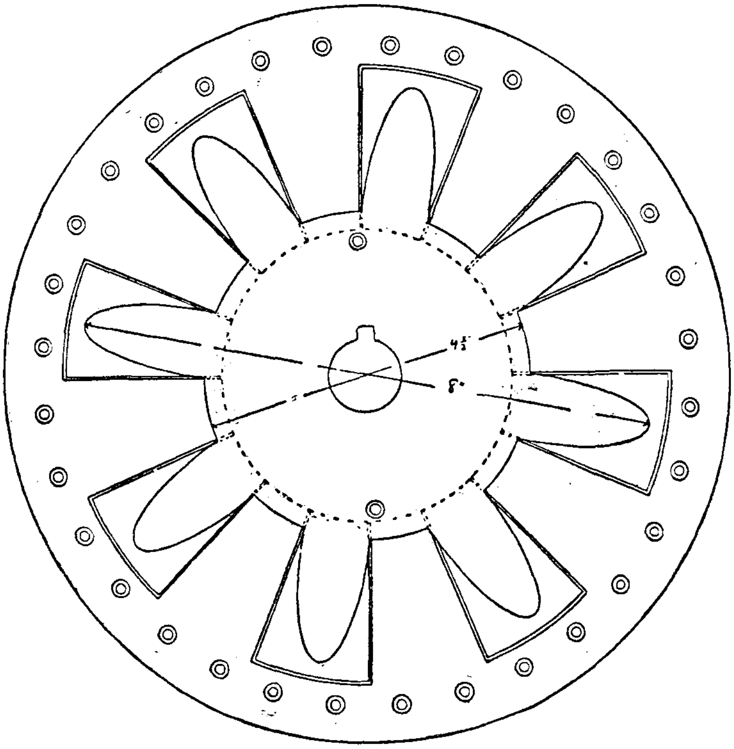


FIG. 3 FIELD MAGNET AND ARMATURE

The first test to which the apparatus was put was to obtain the judgment of a person having a trained ear as to the quality of the tone produced by its current in a telephone. His opinion was that the tone was pure, only the fundamental being detected. The wave form was then mapped.

In planning this work it occurred to us to employ the method of projection of potential whenever it was necessary to measure a P. D. or E. M. F. at any instant. The opposing P. D. was obtained by the fall of potential due to the passage of a direct current through a suitable resistance. As the opposing P. D. was not alternating, the above mentioned contact arrangement was used in place of the ordinary key, and its value was determined by a suitable Weston voltmeter. This method of dealing with instantaneous E. M. F.'s was originally suggested by Professors Foster and Maxwell, their object

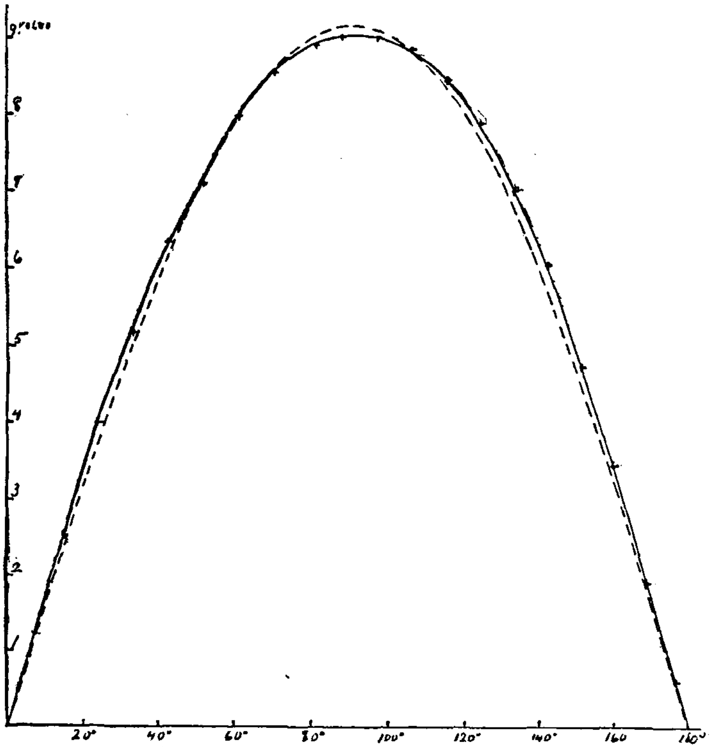


Fig. 4 Armature A. True Sine Curve Dotted.

being to obtain a balance between a known E. M. F. and the P. D. between the terminals of a resistance through which a current of known absolute magnitude was flowing.*

In order to obtain sensitiveness at the final balancing, a condenser one microfarad in capacity was inserted in shunt with the galvanometer, the discharge of the condenser serving to increase the deflection. The galvanometer was of 3,000 ohms' resistance. A telephone was used to obtain the preliminary balance. In Table I. are given the results of the determination of the wave forms of both dynamos, one section of 10 wires being used. In the case of armature A (movable) a series of checks is appended. The whole series was gone through with and then repeated in the reverse direction, the person making

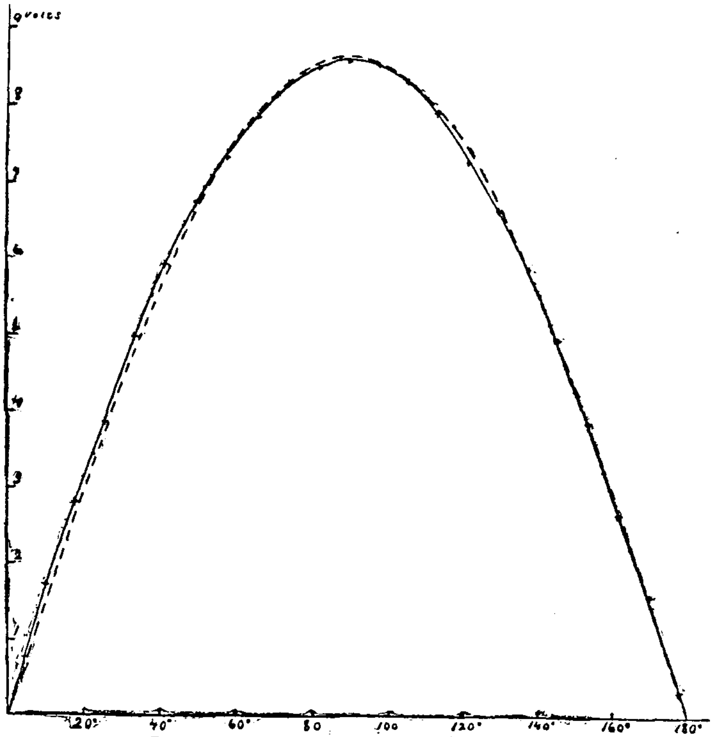


FIG 5 ARMATURE B. TRUE SINE CURVE DOTTED.

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* Telegraphic Journal, 1874, II. 317.

TABLE I. — DETERMINATION OF WAVE FORM.

ARMATURE A. Ampere Turns, 2,875. — Speed, 1,465.			ARMATURE B. Ampere Turns, 2,150.	
Revs. of Mic. Head.	E. M. F. in Volts.	Check.	Position of Contact.	E. M. F. in Volts.
0	+0.49	+0.48	11°	+1.00
½	—0.91	—1.20	10	—0.26
1	—2.52	—2.53	9	—1.72
1½	—4.01	—4.01	8	—2.80
2	—5.21	—5.19	7	—3.86
2½	—6.38	—6.36	6	—4.98
3	—7.09	—7.21	5	—5.93
3½	—8.04	—8.03	4	—6.75
4	—8.61	—8.61	3	—7.34
4½	—9.01	—8.96	2	—7.86
5	—9.11	—9.12	1	—8.30
5½	—9.12	—9.12	360	—8.50
6	—8.95	—8.94	359	—8.56
6½	—8.52	—8.54	358	—8.54
7	—8.00	—7.95	357	—8.30
7½	—7.09	—7.08	356	—7.91
8	—6.11	—6.12	355	—7.26
8½	—4.80	—4.80	354	—6.62
9	—3.53	—3.48	353	—5.86
9½	—1.94	—1.96	352	—4.93
10	—0.60	—0.60	351	—3.85
10½	+1.12	—	350	—2.67
—	—	—	349	—1.60
—	—	—	348	—0.32
—	—	—	347	+0.74

the readings not knowing the previous results. The most probable sources of deviation are backlash, variations of field' current, and change of speed. The checks show sufficient precision of the apparatus for the method of procedure to be described presently.

These results are plotted together with true sine curves in Figures 4 and 5. The curves proved to be very nearly symmetrical, so that only one half has been given. The saturation curve connecting maximum E. M. F. and field current was taken with armature A. The results are given below, and are plotted in Figure 6.

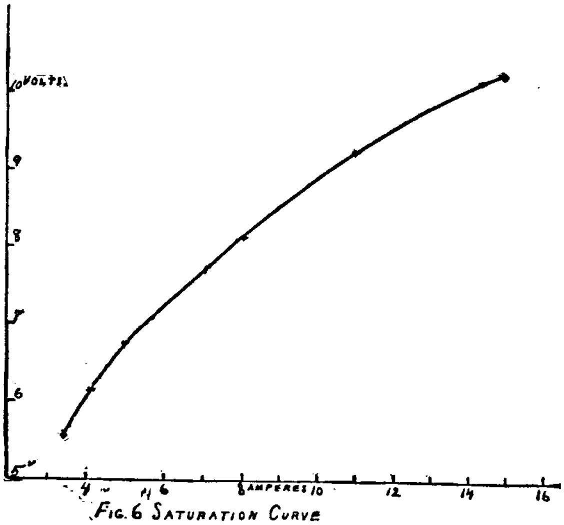

Fig. 6 Saturation Curve

TABLE II. — Data of Saturation Curve.

Speed, 1,465.

Field Current in Amperes.	E. M. F. in Volts.	Field Current in Amperes.	E. M. F. in Volts.
3.40	5.56	8.06	8.10
4.12	6.16	9.38	8.52
4.93	6.74	11.12	9.23
6.10	7.40	14.40	10.10
7.08	7.70	15.00	10.18

METHODS OF USING THE MACHINE.

The following methods are all based on the assumption that we have a sinusoidal E. M. F. of known period, acting in a circuit containing only true resistances and inductances. The current at any instant will be expressed by the equation

$$i = \frac{E}{\sqrt{R^2 + P^2L^2}} \sin \left(Pt - \tan^{-1}\frac{LP}{R}\right).$$

The maximum value of the sine term being unity, we have

$$\frac{I}{E} = \frac{1}{\sqrt{R^2 + P^2L^2}},$$

I and E being the maximum current in, and maximum E. M. F. impressed upon, the part of the circuit under discussion. Also the lag between current and E. M. F. is expressed by $\tan \theta = \frac{LP}{R}$. From these two equations we have

$$L = \frac{E}{IP} \sin \theta. \quad \text{and} \quad R = \frac{E}{I} \cos \theta.$$

Our aim is, therefore, to obtain the values of the impedance, angle of lag, and frequency, and to calculate the coefficient of self-induction and the resistance for any given periodicity by the above formulæ.

(*a*) If we make up a circuit of the movable armature, a known resistance of negligible inductance, and the unknown coil, all in series, we may, by means of the measuring arrangement already mentioned, obtain E and I, the latter by the maximum P. D. around the known resistance. The angle θ would best be found by taking measurements on both sides of the zeros of current and E. M. F., and interpolating for the zero points. The difference of readings of the micrometer so obtained divided by 20 gives the angle θ. L and R are to be calculated by the above formulæ.

(*b*) If we have a carefully made plot, like Figure 6, connecting the maximum E. M. F. and field current of one dynamo, we may proceed as follows. As the wave forms are alike, both following the sinusoidal law, we may apply Poggendorf's method of balancing E. M. F.'s directly, using a suitable telephone instead of a galvanometer. To do this make up a circuit of the stationary armature, known inductionless resistance, and unknown coil. Keep the field current of this dynamo constant. Attach the second armature through the telephone, first to the terminals of the known resistance. Adjust the phase relation for a minimum of sound in the telephone; then adjust for silence by varying the field current. Read the micrometer head and value of exciting current. Repeat this process at the terminals of the unknown coil. These measurements furnish the data necessary for the calculation of L and R. θ is given by difference of micrometer readings divided by 20, as before. Owing to lack of exact similarity of E. M. F. waves it would be necessary in practice to adjust by a minimum, annulling the fundamental.

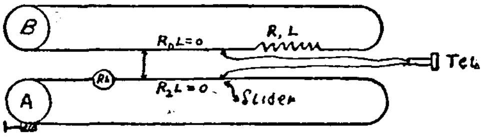

FIG. 7.

(*c*) The trouble of taking the preliminary curve, as well as any uncertainty which its use may introduce, can be avoided by the connections shown in Figure 7.

This method differs from the preceding only in the use of a derived E. M. F. for balancing, and in the method of its adjustment. For convenience give R_1 such a value that the P. D.'s around R_1 and R shall be about equal. Adjust the phase of Armature A by the tangent screw, and adjust for amplitude by varying the field current, final adjustment being obtained by the slider.

Now change the connection to the terminals of the unknown coil, and again adjust for silence, making the adjustment for amplitude in this case by the slider alone. If the two values of the slider resistance are R_2 and R_3, then $\frac{I}{E} = \frac{R_2}{R_1 R_3}$. θ is given by the micrometer head as before.

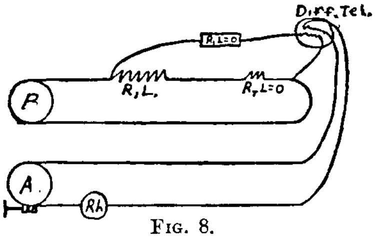

FIG. 8.

(*d*) We may use a differential telephone, that is, a telephone having two opposed windings of equal influence and resistance, in the manner shown in Figure 8.

R_T is a resistance equal to that of one coil of the telephone and of negligible inductance. Adjustment is to be made until with the same value of i_A the telephone is silent when in place, as shown, and when interchanged with R_T then $R_1 = \frac{E}{I}$. θ is given by micrometer readings as before.

(*e*) We may also use the differential telephone to indicate when an unknown inductance is neutralized by a condenser of known variable capacity, by placing one of its coils in series with the inductance and condenser, and the other in series with a variable inductionless resistance R_1, shunted around the above condenser, inductance, and telephone coil, if the resistance R_1 and capacity C be varied until silence is obtained. Then $L = \frac{1}{CP^2}$ and $R = R_1$. It will be desirable to employ an air-condenser to eliminate absorption effects, though this procedure has the disadvantage of requiring a very bulky and costly condenser when small inductances are to be measured.

With this apparatus we may also determine the electrostatic capacity of a condenser when not complicated by absorption effects. For instance, by the first method, we should insert in series with the condenser an inductionless resistance of such a magnitude that the angle of advance could be determined with accuracy.

Then

$$\frac{I}{E} = \frac{1}{\sqrt{R^2 + \frac{1}{C^2P^2}}}, \qquad \tan\psi = \frac{1}{CRP},$$

$$C = \frac{I}{EP\sin\psi}, \quad \text{and} \quad R = \frac{E}{I}\cos\psi.$$

If $R = 0$, $\psi = 90°$ and $C = \frac{I}{EP}$.

The above are the chief uses to which the apparatus may be put. We hope in the near future to investigate the transmission of telephonic and telegraphic signals, and to study various small induction coils such as are used in telephony, as well as the errors introduced into results by the above methods owing to lack of fulfilment of the assumed law by the E. M. F.

Rogers Laboratory of Physics,
September, 1893.

XIV.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, NO. VI.

By B. L. Robinson.

Presented January 10, 1894.

I. — THE NORTH AMERICAN ALSINEÆ.

The following provisional treatment of the North American *Alsineæ* is based principally upon the material in the Gray Herbarium. An effort, however, has been made to see as large a representation of the group as possible, and with this end in view a number of other large and valuable collections have been visited; namely, the herbaria of the Department of Agriculture, Columbia College, the Missouri Botanical Garden, the Philadelphia Academy of Natural Sciences, the Boston Natural History Society, and the private collections of Mr. William M. Canby of Wilmington, Del., Mr. John Donnell Smith of Baltimore, and Mr. Walter Deane and Mr. Edward L. Rand of Cambridge, Mass. Those in charge of all these collections have most kindly allowed their *Caryophyllaceæ* to be examined, and all such specimens as showed any noteworthy peculiarities to be brought to Cambridge for critical study. From the herbaria of the Canadian Geological Survey, Iowa Agricultural College, and Natural History Society of Wilmington, Del., the entire representation of *Alsineæ* has also been most obligingly forwarded to the Gray Herbarium for examination.

While the study of such copious materials has obvious advantages, it by no means lessens, but rather increases, the difficulties of classification. In a long series of specimens individual variation becomes apparent in a way which can scarcely be realized if study is confined to fewer plants. Specific limitations often become very obscure, and sharp definition almost or quite impossible. Several instances of such practically confluent species occur in the present group, and in adjusting specific lines there is consequently great room for difference of opinion. Free criticism and friendly aid will be very welcome, as much may thus be contributed to fulness and accuracy in the final treatment of this group for the "Synoptical Flora." To the botanists, both professional and amateur, who have most kindly assisted the author in his work upon the present paper, he would express sincere appreciation and cordial thanks. To the following he is especially indebted: Professors William Trelease and N. L. Britton, Mr. J. H. Redfield, Mr. F. V. Coville, Dr. J. N. Rose, Mrs. T. S. Brandegee, Miss M. E. Carter, Professor J. Macoun and Mr. J. M. Macoun, Professors T. C. Porter, L. H. Pammel, W. W. Bailey, and O. D. Allen, Messrs. William M. Canby, John Donnell Smith, Walter Deane, Edward L. Rand, Theodor Holm, and J. F. Collins. In the study of *Spergularia* an extensive series of Californian forms of that difficult genus, contributed to the Gray Herbarium by Mrs. T. S. Brandegee, has proved invaluable. In matters of synonymy and the citation of literature Dr. Watson's *Bibliographical Index* has again been a most useful guide.

CARYOPHYLLACEÆ, Tribe I. SILENEÆ. Including genera 1–7. (See Proc. Am. Acad. xxviii. 124.)

Tribe II. ALSINEÆ. Sepals free or slightly united at the very base. Petals more or less contracted but not unguiculate below. Corona absent. Flowers mostly small. Styles distinct to the base.

* Stipules none.

+ Capsule cylindric, more or less elongated, often curved, dehiscent by twice as many teeth as there are carpels.

8. **Holosteum.** Sepals 5. Petals 5, white, subentire or denticulate toward the apex. Stamens 3–5, very rarely 10. Styles 3 (occasionally 4 or 5), longitudinally stigmatic. Pod unicellular. Seeds numerous, dorsally flattened, i. e. parallel with the incumbent cotyledons; the radicle prominent upon the ventral surface. Inflorescence umbelliform.

9. **Cerastium.** Sepals in our species 5. Petals as many, retuse or bifid, very rarely subentire, white. Stamens 10, or sometimes fewer. Styles 5 (4 or 3). Capsule usually exceeding the calyx, often curved. Seeds numerous, more or less laterally compressed.

+ + Capsule ovoid or oblong relatively short, dehiscent by as many or twice as many teeth as there are carpels.

++ Styles usually fewer than the sepals, when of the same number opposite them.

10. **Stellaria.** Sepals 5 (–4). Petals 5 (–4, rarely abortive or absent), always more or less deeply bifid, often divided almost to the base, white. Stamens 3–10. Styles 3–4, rarely 5.

11. Arenaria. Sepals 5. Petals as many, white or nearly so, entire or emarginate (very rarely minute or wanting). Stamens 10, or often fewer by abortion. Styles 3 or 4. Seeds many.

+ + Styles as many as the sepals and alternate with them.

12. Sagina. Sepals 5, (rarely 4). Petals as many, entire or emarginate, white, rarely obsolete. Stamens usually 5, less frequently 3–10. Valves of the capsule as many as the sepals, and opposite them. Seeds several to many.

* * Stipules present, scarious: petals undivided.

13. Spergularia. Sepals 5. Petals 5 (rarely fewer or none), reddish or white. Stamens commonly 10. Styles 3 (very rarely 5); ovary 1-celled; valves of the capsule as many as the styles, when 5 in number alternate with the sepals. Seeds often margined. Leaves linear or filiform.

14. Spergula. Sepals 5. Petals 5. Stamens 10 (rarely 5). Styles 5; ovary unilocular, many-ovuled. Valves of the capsule 5, opposite the sepals. Seeds acutely margined or narrowly winged. Leaves narrow, linear, verticillate and fascicled in the axils.

TRIBE III. POLYCARPEÆ. Including genera 15–18. (See Proc. Am. Acad. xxviii. 126.)

8. **HOLOSTEUM**, L. (ὅλος, all, and ὀστέον, bone; used ironically, since the plants are soft and weak.) — A small genus of Old World annuals and biennials much resembling *Cerastium* except in inflorescence and seeds. The commonest species is adventive in America. — Gen. no. 928; Reichb. Icon. Fl. Germ. v. t. 221; Gay, Ann. Sci. Nat. ser. 3, iv. 23; Benth. & Hook. Gen. i. 148.

H. UMBELLATUM, L. Finely glandular-pubescent, somewhat glaucous: stems 3–18 inches high: leaves sessile, ovate-oblong: umbels 3–12-flowered, terminal upon long naked peduncles; pedicels 8–12 lines long, some of them reflexed: filaments shorter than the calyx. — Spec. 88; Eng. Bot. i. 27. Locally naturalized in Pennsylvania, New Jersey, and Delaware, *Porter*, *Austin*, *Canby*, *Small.* (Adv. from Eur.)

9. **CERASTIUM**, L. MOUSE-EAR CHICKWEED. (κέρας, a horn, from the elongated curved capsules.) — Annuals or perennials, usually pubescent and often viscid. Leaves usually flat. Flowers white, borne in more or less expanded leafy or naked cymes. A genus distinguished from *Stellaria* and *Arenaria* somewhat by habit, but chiefly, although not always satisfactorily, by the form and dehiscence

of the capsule. — Gen. no. 376; Seringe in DC. Prodr. i. 414; Grenier, Flora, 1840, pt. 1, 266; Reichb. Icon. Fl. Germ. v.–vi. t. 228–236; Benth. & Hook. Gen. i. 148; Pax in Engl. & Prantl, Nat. Pflanzenf. iii. 1 b, 80.

§ 1. STREPHODON, Seringe, l. c. Styles 3–5: teeth of the capsule finally circinate-revolute from the tip. — Our species have pubescent leaves.

C. **Texanum**, BRITTON. Annual, viscid: stems several, slender, nearly erect, leafy below, nearly naked and dichotomous above: leaves oblanceolate or spatulate, 6 lines to 2 inches in length, very pubescent or subcinereous on both surfaces: flowers rather small: petals bifid: styles 3–4 (–5?): capsule 1½–2 times the length of the calyx. — Bull. Torr. Club, xv. 97. — Hills, Blanco, Texas, *Wright;* New Mexico on the Mongollons, *Greene;* Arizona, Santa Cataline Mts., *Lemmon.* (Mex., *Palmer;* Lower Calif., *Brandegee.*)

C. **maximum**, L. Stoloniferous perennial with stems simple or nearly so, erect or decumbent, becoming a foot or more in height: leaves linear or lanceolate, attenuate: flowers very large for the genus, 1 inch in diameter, borne on erect pedicels in simple or branched cymes: sepals oblong or narrowly ovate, obtuse, 3–4 lines long: petals obovate, much exceeding the calyx, deeply notched at the apex: capsule symmetrical, much exserted at maturity. — Spec. 439; Ledeb. Icon. Fl. Ross. t. 242; Fenzl in Ledeb. Fl. Ross. i. 399; Seem. Bot. Herald, 51. *C. grande*, Greene, Pitt. ii. 229. — Alaska. (Siberia.) Asiatic specimens of this species, identified at the St. Petersburg Gardens, show that the capsule becomes cylindric and much longer than figured by Ledebour.

§ 2. ORTHODON, Seringe. Styles normally 5: teeth of capsule erect or spreading; the edges sometimes slightly reflexed. — DC. Prodr. i. 415. — Our species have pubescent leaves.

* Flowers comparatively small: petals 1–1½ times as long as the sepals.

+ Pods 1–1¾ times as long as the calyx: introduced or doubtfully indigenous weeds.

C. VISCOSUM, L. (MOUSE-EAR CHICKWEED.) Annual, viscid pubescent, 3 inches to a span high: leaves oval or elliptic-oblong, very obtuse; the lowest narrowed below to a short margined petiole: flowers small, at first densely clustered at the ends of the branches, becoming laxer in fruit, but even the longest pedicels not exceeding the acute sepals (1¾–2 lines in length): bracts herbaceous: petals scarcely equalling the calyx: stamens frequently 5. — Spec. 437; Hook. f. Arc. Pl. 288; Wats. Bibl. Index, 101; Wats. & Coulter in

Gray, Man. ed. 6, 88. *C. vulgatum*, Linn. in herb.; Torr. & Gray, Fl. i. 187; Gray, Man. eds. 1–5; and others. *C. hirsutum*, Muhl. Cat. 46. *C. glomeratum*, Thuill. as used by Hooker, f. and others. *C. connatum*, Beck, Bot. 55. Depauperate forms with few flowers and short capsule have been regarded as indigenous, being the *C. viscosum*, var. *tenellum*, Grenier, l. c. 266, and the *C. semidecandrum*, auct. (not of Linn.). — Widely distributed in the United States and Canada, but much less common than the following; probably introduced from Europe. Delicate specimens apparently to be referred to this species, but with minute apetalous flowers, have been collected at San Diego, Calif., *Orcutt.*

C. VULGATUM, L. (COMMON MOUSE-EAR CHICKWEED.) Perennial, viscid-pubescent, a little taller and more spreading than the last: leaves oblong, obtusely pointed: flowers larger: the lower pedicels in fruit considerably exceeding the calyx: bracts herbaceous: sepals 2–3 lines long, obtuse, often purple-tipped, appearing acute through the infolding of the scarious margins: petals as long as the calyx. — Spec. ed. 2, 627; Regel, Ost-Sib. i. 432; Wats. Bibl. Index, 101; Wats. & Coulter in Gray, Man. ed. 6, 88. *C. viscosum*, Linn. in herb.; Torr. & Gray, Fl. i. 187; Gray, Man. eds. 1–5, etc. *C. fulvum*, Raf. Préc. Découv. 36. *C. triviale*, Link, Enum. Hort. Berol. i. 433. — Very common in fields, etc., but also often remote from habitations and cultivated ground, thus perhaps native. Flowering through the summer.

C. SEMIDECANDRUM, L. Near the two preceding, but smaller and with shorter leaves: the bracts, at least the upper ones, conspicuously scarious-margined: pedicels in fruit longer than the calyx. — Spec. 438; *C. vulgatum*, var. ? *semidecandrum*, Gray, Man. ed. 5, 94. — New Jersey, *Britton*, *Peters*, to Norfolk, Va., *Britton*, *Small.* (Adventive from Europe.)

+ + Pods 2–3 times as long as the calyx: indigenous species.

C. brachypodum. Pale green, finely pubescent and sometimes very viscid: leaves linear-oblong to oblanceolate, obtusish, seldom more than an inch in length: flowers in more or less open dichotomous cymes; pedicels, even the lower ones, only equalling or little exceeding the capsules, erect or deflexed, straight or gently curved, not hooked. — *C. nutans*, Raf., var. *brachypodum*, Engelm. in herb. — St. Louis, Mo., *Engelmann*, April, 1842, April–May, 1845; westward and southward to Nevada, *Anderson*, 238, *Watson*, 156; Arizona, *Palmer*; New Mexico, *Fendler*, 61; Texas, *Wright.* (Mex. *Schaffner*, *Palmer.*) *C. tenellum*, Fenzl, mentioned in Watson's Index (but never published?), represented by Drummond's no. 30 of his 3d Texan Coll., appears to be only a more slender form of the above. Exactly the same thing, however, has been found at Milledgeville, Ga., by Dr. Boykin (Short Herbarium), thus considerably extending the range of the species. In raising Dr. Engelmann's variety to specific rank I follow the suggestion of Dr. N. L. Britton. Certainly, the more restricted geographic range and the absence of connecting forms indicate its distinctness from *C. nutans.* A very leafy and velvety tomentose form from Willow Spring, Arizona, *Palmer,* is worthy of mention.

Var. compactum. Inflorescence capitate-umbellate: pods very slender. — *C. nutans,* Raf., var. *compactum,* Engelm. in herb. — A marked variety or form from the Bad Lands of Nebraska, *Hayden;* Belknap, N. Texas, *Hayes;* False Washita, Ind. Terr., *Palmer,* 1868.

C. nutans, Raf. A pubescent and viscid annual, 8–18 inches high: stems branched: leaves oblong-lanceolate, acute; the lowest narrowed toward the base: flowers numerous in an open dichotomous cyme: calyx about 2 lines in length: petals somewhat exserted, oblanceolate, bifid: pedicels elongated, ascending or spreading, tending to be hooked or nodding at the summit: capsule 4–6 lines long, nodding but curved upward. — Préc. Découv. 36, & Desv. Journ. Bot. iv. 269 (1814); Gray, Gen. ii. t. 114. *C. longepedunculatum,* Muhl. Cat. 46. *C. glutinosum,* Nutt. Gen. i. 291. *C. apricum,* Schlecht. Linnæa, xii. 208. *C. oblongifolium,* Anderson, Cat. Pl. Nev. 118. — Common and widely distributed from New England to the Pacific and from Hudson Bay to New Mexico. Like the last, paler green than the other common species. Apetalous specimens have been found at Wawa, Penn., *Brinton.* Arizona forms of this species also differ slightly in habit, but lack technical characters for satisfactory distinction.

C. sericeum, Wats. Annual: stems one or many, 1–2 feet high, stout for the genus, sericeous, very leafy below: leaves oblong-lanceolate, sessile, 1–2 inches long, 3–6 lines broad; the lower cinereous with dense flocculent wool; the upper green: flowers numerous in spreading cymes: calyx 2½ lines long, scarcely exceeded by the corolla. — Proc. Am. Acad. xx. 354. — S. Arizona in the Huachuca Mts., *Lemmon;* Santa Rita Mts., *Pringle.*

* * Flowers large; petals usually twice as long as the calyx: indigenous species.

C. arvense, L. Perennial: stems several, weak, usually almost naked above: leaves linear to narrowly lance-oblong: petals obcordate: pod in the typical form scarcely longer than the calyx. — Spec. 438; Hook. Fl. Bor.-Am. i. 104; Torr. & Gray, Fl. i. 188; Hollick & Britton, Bull. Torr. Club, xiv. 45. ? *C. hybridum*, Muhl. Trans. Am. Phil. Soc. ser. 1, iii. 170. *C. Pennsylvanicum*, Hornem. Hart. Hafn. 435. — Rocky soil, common; May–July. (Eu., Asia, & S. Amer.) Very variable in size, pubescence, relative length of its capsules, etc. Var. ANGUSTIFOLIUM, Fenzl, l. c. i. 413, with cauline leaves narrowly oblong to linear, attenuate at the base, much fascicled and 9–15 lines in length, and var. LATIFOLIUM, Fenzl, l. c. i. 412, with shorter oblong leaves, 6–8 lines long, broad at the base, are forms strikingly different in their extremes, but rather freely intergrading and often difficult to distinguish. The latter is perhaps a little more common in the Rocky Mountains but extends eastward to Labrador. Better marked are the following.

Var. oblongifolium, HOLLICK & BRITTON. Leaves oblong or lance-oblong, obtuse or obtusish: capsule longer, 1½–2½ times as long as the calyx. — Bull. Torr. Club, xiv. 47, t. lxiii. *C. oblongifolium*, Torr. Fl. U. S. 460; Torr. & Gray, Fl. i. 188. ? *C. dichotomum*, Muhl. Cat. 46. ? *C. bracteatum*, Raf. Préc. Découv. 36. — Nova Scotia to Virginia, and Montana, *Scribner*, to New Mexico, *Vasey*. This variety has been widely drawn by its authors to include narrow-leaved forms as well as the original rather broad-leaved *C. oblongifolium*, extended series of specimens showing complete transitions.

Var. maximum, HOLLICK & BRITTON, l. c. xiv. 47. Taller, 1–2 feet high: leaves elongated, lanceolate, acutish, 2–3 lines broad: inflorescence very spreading: capsule equalling or half exceeding the calyx. — *C. oblongifolium*, Torr. Pacif. R. Rep. iv. 70. *C. pilosum*, Brew. & Wats., Bot. Calif. i. 67, not of Ledeb. — Dixon, Ill., *Vasey*, and in California, Punta de los Reyes, *Bigelow*, and elsewhere. Scarcely more than a rank growing form, but serving to connect the next species through var. *Fischerianum*.

Var. villosum, HOLLICK & BRITTON, l. c. xiv. 49. Densely villous: leaves rather broadly lanceolate. — *C. velutinum*, Raf. Med. Rep. (hex. 2), v. 359. *C. villosum*, Muhl. Cat. 46. Darlingt. Fl. Cest. ed. 2. 279. ? *C. hirsutum*, Darlingt. Florula Cest. 54. *C. oblongifolium*, Torr. & Gray, Fl. i. 188 in part; Wats. Bibl. Index, 101. — Lancaster Co., Penn., *Porter*.

Var. Fuegianum, HOOK. f. Depauperate, 2–3 inches high, with short thickish imbricated leaves and sub-solitary terminal flowers. — U. S. Expl. Exped. 119. — Specimens collected by *Coulter* in the

Yellowstone Park have been confidently referred to this variety by Hollick and Britton, l. c., and *Parry's* no. 41 from Northwestern Wyoming is doubtless the same.

C. alpinum, L. Densely silky: stems weak, matted: leaves elliptic-ovate, in the typical form only 4–5 lines long: petals notched at the apex, 1½–2 times the length of the sepals. — Spec. 438; Torr. & Gray, Fl. i. 188; Regel, Ost-Sib. i. 433, 434. *C. lanatum*, Lam. Encycl. i. 680. *C. latifolium*, Greville, Mem. Soc. Wern. iii. 429. *C. vulgatum*, Hook. f. Arc. Pl. 288 in part. ? *C. latifolium*, Hart., Trimen's Journ. of Bot. ix. 205. — Arctic America from Greenland to Alaska, also in Labrador, the Hudson Bay region, and upon the Rocky Mountains of British America. (Europe and Asia.) The following varieties extend farther southward.

Var. Beeringianum, Regel. Hirsute and less silky-villous, somewhat viscid above: leaves smaller, oblong. — Ost-Sib. i. 435. *C. Beeringianum*, Cham. & Schlecht., Linnæa, i. 62. *C. vulgatum*, var. *Beeringianum*, Fenzl in Ledeb. Fl. Ross. i. 409. — Alaska to the Rocky Mountains of Colorado and Arizona.

Var. Fischerianum, Torr. & Gray. Hirsute, taller, 8–10 inches or even more than a foot in height: leaves rather thick, elliptic-lanceolate or oval-lanceolate, acute or acutish, an inch or more in length: capsule 1½–2 (or rarely 3) times the length of the calyx. — Fl. i. 188; Regel, l. c. i. 438. *C. rigidum*, Ledeb. Mem. Petr. v. 538. *C. Fischerianum*, Seringe in DC. Prodr. i. 419. *C. vulgatum*, vars. *grandiflorum* and *macrocarpum*, Fenzl in Ledeb. Fl. Ross. i. 409, 410. To judge from the figure in the Calques des Dessins *C. stellarioides*, Moç. should be referred here also, having been placed by Seringe probably through error in § *Strephodon*. — A stout variety passing to *C. arvense*, var. *maximum*, but with broader more elliptic-ovate leaves and longer capsules. Alaska to Humboldt Co., Calif., *Rattan*. (Siberia, Japan.) The leaves are thicker and the sepals more pubescent and acute than in *C. pilosum*, Ledeb., to which it is also nearly related.

Var. glabratum, Hook. Leaves and calyx nearly smooth. — Parry's 2d Voy. 390; Fl. Bor.-Am. i. 104. — Arctic America with the pubescent forms. (N. Eur.)

§ 3. Dichodon, Bartl. Styles normally 3: teeth of the capsule erect or slightly spreading, not circinate-revolute. — Endl. Gen. 970. — Our species with symmetrical capsule and short glabrous leaves.

C. trigynum, Vill. Perennial, with stems weak, spreading, somewhat matted, smooth or glandular-pubescent, loosely 2–3 flowered:

leaves oblong, 3–5 (–8) lines in length; the uppermost ovate: sepals lance-ovate or oblong, obtuse, 2–3 lines long: petals 1½–2 times the length of the calyx, obcordate, bifid nearly half way to the base: capsule oblong-conic, twice the length of the calyx; the teeth finally spreading. — Dauph. iii. 645, t. 46; Fenzl in Ledeb. Fl. Ross. i. 396. *Stellaria cerastoides,* L. Spec. 422; Torr. & Gray, Fl. i. 184; Hook. f. Arc. Pl. 288. — Table-topped Mountain, Gaspe, Lower Canada, *Allen;* Cape Chudleigh, Hudson Strait, *Bell;* Labrador, Greenland, *Holm.* (Europe and Siberia.) A species now generally appended to *Cerastium*, but forming a transition to *Stellaria.*

Mœnchia quaternella, Ehrh. (*Sagina erecta,* L., *Cerastium quaternellum,* Fenzl.) An erect glaucous annual with subsimple stems, 2–3 inches high, bearing 1 or 2 erect 4-parted flowers, was found in the thirties near Baltimore by *B. D. Greene.* It is said to have been recently rediscovered there, but nothing more definite has been learned concerning its American occurrence. (Europe.)

10. STELLARIA, L. Chickweed, Starwort. (*Stella,* a star, in reference to the form of the flower.) — Low spreading herbs, sometimes a little succulent, mostly preferring a moist shaded habitat. Leaves flat or very rarely acerose. A genus conveniently but somewhat artificially separated from Arenaria by the more or less deeply cleft petals. — Spec. 421, & Gen. ed. 5, no. 504; Seringe in DC. Prodr. i. 396; Fenzl in Endl. Gen. 969; Reichb. Icon. Fl. Germ. v. t. 222–226; Benth. & Hook. Gen. i. 149; Gray, Gen. ii. t. 113; Pax in Engl. & Prantl, Nat. Pflanzenf. iii. 1 b, 79. *Spergulastrum,* Michx. Fl. i. 275. *Micropetalon,* Pers. Syn. i. 509. *Larbrea,* St. Hil. Mem. Mus. Par. ii. 287.

§ 1. Myosoton, Mönch (as genus). Styles 5, alternate with the sepals: leaves ovate acute. — Method. 225. *Malachia,* Fries, Fl. Hall. 77.

S. aquatica, Scop. Perennial, with stem strongly angled and somewhat pubescent: leaves large, ovate, or ovate-lanceolate, acute; the upper sessile, cordate; the lower petiolate: pedicels glandular-viscid, deflexed in fruit: petals 1½–2 times as long as the campanulate glandular-pubescent calyx: seeds numerous, dark-colored, tuberculately roughened. — Fl. Carn. ed. 2, i. 319. *Malachia aquatica,* Fries, Fl. Hall. 77. *Larbrea aquatica,* Seringe in DC. Prodr. i. 395 (excl. synon.). — Becoming frequent upon waste land and public grounds in the Eastern States, and more or less established along roadsides in British America, Stratford, Ont., *Burgess;* Nanaimo, B. C., *Macoun.* (Adventive from Europe.)

§ 2. EUSTELLARIA, Fenzl, l. c. 969. Styles 3–4.

* Petals, except in some flowers of *S. pubera*, very deeply 2-parted (sometimes minute or wanting): segments narrow.

+ Lower leaves ovate, rather abruptly contracted into slender petioles.

S. MEDIA, Smith. (COMMON CHICKWEED.) A low annual: stem pubescent in lines: leaves acute; the upper narrower sessile, the lower on pubescent narrowly margined petioles: calyx glandular-pubescent, equalled or slightly exceeded by the capsule: petals shorter than the sepals: stamens 3, 5, or 10. — Eng. Bot. viii. t. 537. *Alsine media*, L. Spec. 272; Walt. Car. 117. *Holosteum succulentum*, L. Amœn. iii. 21; Nutt. Gen. i. 89; Torr. Fl. U. S. 159. — One of the commonest weeds in dooryards and cultivated grounds, especially in moist soil, flowering from early spring to late autumn.

S. prostrata, BALDW. Annual: stems weak, elongated, prostrate, pubescent: leaves ovate, acute or shortly acuminate, the lower subcordate on slender ciliated petioles; the upper cauline short-petioled or sub-sessile; the floral reduced and bractlike: pedicels filiform: flowers smaller than in the preceding: sepals in anthesis but a line long: petals nearly twice as long: mature capsule much exceeding the calyx; valves distinctly circinate-revolute. — Baldw. in Ell. Sk. i. 518; Torr. & Gray, Fl. i. 183; Gray, Pl. Lindh. ii. 152, & Pl. Wright. ii. 17; Chapm. Fl. 50. — Moist and shaded places, rocky woods; Georgia and Florida to Texas. (Adj. Mex.) Leaves very variable in size, from 2 lines to an inch in length. The flowers in this species are distinctly smaller than in the nearly related Mexican *S. cuspidata*, Willd., and *S. ovata*, Willd.

S. nitens, NUTT. Annual, slender, erect, shining: stems filiform, forked several times, leafy and slightly pubescent near the base, almost naked and quite glabrous above: leaves of two forms, the lowest (1–3 pairs) ovate, acute, only 2 lines long, on slender petioles of somewhat greater length, not always persisting; the other leaves lance-linear acute, 3–5 lines long: sepals very acute, scarious-margined, 1–3 nerved: petals half as long as the sepals, sometimes absent: capsule oblong, about equalling the calyx. — Torr. & Gray, Fl. i. 185; Torr. Pacif. R. Rep. iv. 69, & Bot. Mex. Bound. 37; Gray, Proc. Am. Acad. viii. 378. *S. mœnchioides*, Fenzl, acc. to Torr. & Gray, Fl. i. 675. *S. stricta*, Hook. Fl. Bor.-Am. i. 96 in part. — S. California to Brit. Columbia, *Macoun*; eastward to Utah, *Jones*; April, May.

S. GRAMINEA, L., with seldom persistent but sometimes slightly petiolate lower leaves, may possibly be sought here.

+ + Leaves acerose.

S. Kingii, Wats. Cespitose, minutely glandular-pubescent above: root woody: stems several, 2–7 inches high: leaves crowded below, rigid, pungent, light green: sepals spreading or somewhat reflexed during anthesis, scarious-margined, exceeded by the narrow petals. — Bot. King Exp. 39, t. vi. f. 1–3; Brew. & Wats. Bot. Calif. i. 68. — Humboldt Mts., N. Nevada, *Watson;* S. Utah, *Parry, Palmer;* July and August.

+ + + Leaves all sessile or subsessile, sometimes narrow, but not acerose.

++ Bracts small, scarious.

= Flowers small: petals minute or none.

S. umbellata, Turcz. Smooth: stems weak, ascending from a decumbent rooting base: leaves varying from lanceolate and acute to elliptic-oblong, 3–8 lines in length: pedicels filiform, sub-umbellately grouped at the ends of the branches, often deflexed: sepals small, 1–1¼ lines in length, glabrous, scarious-margined: capsule twice as long; the valves deeply 2-toothed; teeth obtuse. — Cat. Baic. 5, & Fl. Baic.-Dahur. i. 236; Fenzl in Ledeb. Fl. Ross. i. 394; Regel, Ost-Sib. i. 383, 399; Wats. Bot. King Exp. 38; Porter & Coulter, Fl. Col. 13; Brew. & Wats. Bot. Calif. i. 67. *S. borealis*, var. Hook. Fl. Bor.-Am. i. 94. — Mountains of Colorado and Arizona to Union Co., Oregon, *Cusick.* (Asia.)

= = Flowers of medium size: petals equalling or exceeding the calyx (except sometimes in *S. uliginosa*).

a. Seeds essentially smooth.

S. longifolia, Muhl. Stems sharply 4-angled, commonly 8 inches or more in height: leaves linear or linear-oblong, somewhat narrowed at each end, thickish, often ciliate toward the base; the larger ones 1¼–1½ inches long: flowers rather numerous in a lateral long-peduncled open cyme; pedicels spreading, horizontal or deflexed: petals and capsule exceeding the sepals: seeds smooth. — Cat. 45; Willd. Enum. 479; Fenzl, l. c. i. 392; Gray, Gen. ii. 38, t. 113, f. 1–5. *S. graminea*, Bigel. Fl. Bost. 110. *Spergulastrum gramineum*, Michx. Fl. i. 276. *Micropetalon gramineum*, Pers. Syn. i. 509. *M. longifolia*, Eat. & Wright, N. A. Bot. ed. 8, 319. — Canada to Maryland and westward to the Rocky Mts.; June and July. (Europe and Asia.)

S. longipes, Goldie. Smooth and shining or more or less glaucous, spreading at the base: branches erect, 3–12 inches high: leaves linear or lance-linear, gradually narrowed from the base to the acute apex, 1-nerved, 8–12 lines in length, spreading: flowers irregularly cymose: peduncles terminal or rarely and tardily somewhat lateral; pedicels elongated, unequal, erect; the lowest often more or less distinctly axillary: sepals oblong-lanceolate: capsule exceeding the calyx, acutish, dark and shining; seeds very smooth. — Edinb. Phil. Journ. vi. 327; Hook. Fl. Bor.-Am. i. 95; Torr. & Gray, vars. α, β, and γ, Fl. i. 184; Fenzl, l. c. i. 386. *S. palustris*, Richardson, Frankl. Journ. 738. *S. stricta*, Richardson, Frankl. 2d Journ. 15. *S. læta*, Torr. Ann. Lyc. N. Y. ii. 169. *S. glauca*, Meyer, Pl. Lab. 93. *S. crassifolia*, Wats. Bot. King Exp. 38. *S. longifolia*, Rothr. Enum. Pl. Cent. Col. 35. ? *Micropetalon gramineum*, James, Cat. 181. — A variable species marked by its long dark-colored acutish capsule and very smooth seeds. It is widely distributed from Maine to Arctic America, and from Alaska (Siberia) southward along the Rocky Mountains to Colorado and on the Pacific slope to San Bernardino, *Parish*. The commoner form has acute sepals and leaves varying imperceptibly from flaccid and spreading to erect and somewhat pungent. (Var. β of Torr. & Gray, Fl. i. 185. *S. stricta*, Richardson, etc.) The typical form with spreading leaves and "very obtuse" sepals is comparatively rare. The following, although the best marked varieties, are connected by innumerable puzzling intermediate forms.

Var. **læta**, Wats. Low, smooth or somewhat pubescent, 1–4 inches in height, usually very glaucous, densely leafy at the base: leaves carinate, lanceolate-subulate to linear, rather rigid, erect, 2–6 lines long, shorter than in the type, narrower than in the following. — Bibl. Index, 112. *S. læta*, Richardson, Frankl. Journ. 738; Hook. in Parry's 2d Voyage, 300, & Fl. Bor.-Am. i. 96. *S. stricta*, var. γ, Hook. l. c. i. 96. *S. longipes*, var. δ, Torr. & Gray, Fl. i. 185. — Arctic America to the Rocky Mountains of Montana and Wyoming to Gaspe, *Allen*. (Siberia.) A very similar form has been found on the coast of New Brunswick, *Fowler*. The variety PEDUNCULARIS of Fenzl is a boreal form somewhat intermediate between this variety and the next, and indefinitely characterized by still more elongated pedicels.

Var. **Edwardsii**, Wats. Low, smooth or pubescent: leaves lanceolate to ovate-lanceolate or even ovate, shorter than in the type: stems usually but 2–3-flowered; the lower peduncles axillary, much longer than the others. — Bibl. Index, 113. *S. Edwardsii*, R. Br. in Parry's 1st Voy. 271, 308; Cham. & Schlecht. Linnæa, i. 48; Hook. Fl. Bor.-Am. i. 96, t. 31; Hornem. Fl. Dan. xiii. t. 2290. *S. nitida*, Hook. in Scoresb. Greenl. 411; Cham. & Schlecht. l. c.

i. 47. — British America from Labrador to British Columbia, northward to the Arctic regions; Alaska. (Siberia.)

b. Seeds distinctly rugose-roughened under a lens.

S. GRAMINEA, L. Stems ascending, smooth and shining, 1–2½ feet high, sharply 4-angled (rhombic in cross-section); internodes usually elongated: leaves lanceolate or lance-linear, thickish, attenuate, furrowed above and with midrib prominent beneath: inflorescence a broad terminal pedunculate cyme, often accompanied by one or two smaller cymes springing at its base; pedicels elongated, spreading, or deflexed: capsule exceeding the calyx. — Spec. 422; Eng. Bot. xii. t. 803; Fenzl in Ledeb. Fl. Ross. i. 391; Wats. & Coulter in Gray, Man. ed. 6, 87. — Introduced in moist grassy places, Nova Scotia to New Jersey, and in Northern States across the continent; common. (Europe.)

S. uliginosa, MURR. Low, weak, diffuse: stems numerous, leafy: leaves lanceolate or elliptic-lanceolate, 6–8 lines long, acute at each end: inflorescences few-flowered, pedunculate or sub-sessile, much smaller than in the last, becoming decidedly lateral, 1½ inches or less in length: flowers smaller and petals relatively shorter than in the related species: sepals very acute, 1¾ lines in length. — Comm. Gött. 1778, 55; Fenzl, l. c. i. 393; Eaton & Wright, N. A. Bot. 442; Warming, Bot. Foren. Festkr. 1890, 216, f. 10. *S. aquatica*, Poll. Palat. i. 429; Torr. & Gray, Fl. i. 186. *S. alsine*, Hoffm. Fl. Germ. i. 153; Muhl. Cat. 45; *S. borealis*, Darlingt. Fl. Cest. 274. *Larbrea uliginosa*, Hook. Fl. Bor.-Am. i. 93. — Swamps, Atlantic slope, Halifax (*Macoun*) to Maryland; rare. (Europe.)

+ + Bracts foliaceous (except in *S. borealis*, var. *corollina*.)

= Leaves narrowly elliptical to lanceolate or linear.

S. longipes, GOLDIE, may be sought here, as weak specimens with solitary terminal long-peduncled flowers do not always show the scarious bracts which are developed in more vigorous plants.

S. borealis, BIGEL. Suberect, 6–10 inches in height, smooth or nearly so: leaves lanceolate, attenuate, 6–18 lines long, with one prominent nerve: pedicels scattered, 8–14 lines in length, often deflexed: sepals ovate-lanceolate, scarious-margined, acute or often narrowed to an obtusish apex: petals much shorter than the calyx or none: capsule narrowly ovoid, acutish, 1½–2 times as long as the sepals; seeds smooth. — Fl. Bost. ed. 2, 182; Torr. & Gray, Fl. i. 185; Fenzl, l. c. i. 381; Vahl, Fl. Dan. xiv. t. 2355. *S. calycantha*, Bong. Sitch. 127. *S. crassifolia*, Boland. Cat. 6. *Spergulastrum* *lanceolatum*, Michx. Fl. i. 275. *Micropetalon lanceolatum*, Pers. Syn. i. 509. *Arenaria calycantha*, Ledeb. Mem. Acad. Petr. v. 534. *A. lateriflora*, Darlingt. Florula Cest. 54. — New England to New Jersey; Mendocino Co., Calif., and northward; flowering in mid summer; frequent.

Var. corollina, Fenzl, l. c. i. 382. Taller: inflorescence spreading and more definitely terminal: bracts reduced, the uppermost more or less scarious: petals usually present: seeds slightly roughened. — *S. brachypetala*, Bong. Sitch. 126; Torr. & Gray, Fl. i. 186. *S. alpestris*, Fries, Mant. i. 10, excl. var. *S. Fenzlii*, Regel, Ost-Sib. i. 399. *S. borealis*, var. *alpestris*, Gray, Man. ed. 5, 93. — Lake Superior, *Robbins*, to Oregon, *Howell*, and northward. (Europe and Asia.)

S. crassifolia, Ehrh. Low, smooth: stems many, weak, ascending or suberect, internodes short: leaves small, numerous, thickish, oblong-lanceolate, acutish, 3–6 lines in length: sepals ovate-lanceolate, acuminate, somewhat exceeded by the petals and capsule: seeds distinctly roughened under a lens. — Beitr. iii. 60; Fenzl, l. c. i. 383; Chapm. Fl. ed. 2, 608; Wats. & Coulter in Gray, Man. ed. 6, 87, excl. Kentucky plant. *S. gracilis*, Richardson, Frankl. Journ. 738; Hook. Fl. Bor.-Am. i. 97; Torr. & Gray, Fl. i. 184. *S. borealis*, var. *β*, Hook. l. c. i. 95. — Labrador, *Martin*, *Allen*, to Illinois, *Vasey*, *Hill*; Montana, *Canby*, and northward.

S. fontinalis. Glabrous, stems regularly and dichotomously branched, 6–12 inches long: branches spreading: leaves spatulate-linear, obtusish, spreading, 5–10 lines long: internodes elongated, 1–2 inches in length: peduncles solitary in the forks of the branches, 1–1½ inches long, ascending: sepals 4–5, oblong, obtuse, 3-nerved: petals none: stamens 4–8: styles 3–4, very short: capsule obtuse, not exceeding the calyx. — *S. crassifolia*, Wats. Bibl. Index, 111 in part; Wats. & Coulter in Gray, Man. ed. 6, 87 in part. *Sagina fontinalis*, Short & Peter, Transylv. Journ. Med. 28, 600; Torr. & Gray, Fl. i. 177. *Spergula fontinalis*, Dietr. Syn. Pl. ii. 1597. — Cliffs of Kentucky River and Elkhorn Creek, Kentucky, *Short & Peter*; Nashville, Tenn., *Gattinger*; April, May. This too little known plant, of distinctly aquatic habit, merits further study with more abundant material. It is certainly distinct from *S. crassifolia*, Ehrh.

S. humifusa, Rottb. Low, densely matted, smooth: stems prostrate or ascending, angulate, shining: leaves elliptic-ovate or oblong, acutish, 2–5 lines long, marcescent: peduncles axillary, 4–7 lines in length: sepals ovate-oblong, acute, narrowly margined: petals somewhat exceeding the calyx: seeds smooth. — Act. Hafn. x. 447, t. 4, f. 14; Torr. & Gray, Fl. i. 184; Fenzl in Ledeb. Fl. Ross. i. 384. *S. marginata*, Cham. & Schlecht. Linnæa, i. 50. *Arenaria thymifolia*, Pursh, Fl. 317; Eaton & Wright, N. A. Bot. 132. *A. Purshiana*, Seringe in DC. Prodr. i. 414; Hook. Fl. Bor.-Am. i. 102. — Salt marshes and boggy slopes, Little Cranberry Island, Maine, *Redfield*, and coast of Oregon, *Howell Bros.*, northward to Alaska and Arctic America. (Greenland; N. Asia.) The commoner form, var. OVALIFOLIA, Fenzl, l. c., has leaves ovate or sub-orbicular, crowded, but 1–3 lines in length; var. OBLONGIFOLIA, Fenzl, l. c., has more elongated internodes and oblong leaves, 4–5 lines long.

S. obtusa, ENGELM. Smooth: stems prostrate, 2–3 inches long: leaves thin, ovate, acute, about 4 lines long, half as broad: flowers solitary, appearing axillary: peduncles 3–4 lines long: sepals ovate, obtuse, hardly at all scarious on the margins: petals none: capsule 1¼–1½ times as long as the calyx, obtuse; seeds brown, under a compound microscope covered with lighter colored oblong tubercles with fringed edges. — Bot. Gaz. vii. 5; Macoun, Cat. Canad. Pl. 76. *S. humifusa*, Macoun, Phænog. & Cryptog. Pl. of Canad. 9. — Anthracite Creek, Colorado, 9,000–10,000 feet, *Brandegee;* near Macleod's Lake, Brit. Columbia, *Macoun;* Kootanie Pass, B. C., *Dawson;* June, July.

S. crispa, CHAM. & SCHLECHT. Smooth, or more rarely pubescent: stems numerous, weak, decumbent: leaves thin, ovate, acuminate, commonly crisped on the edges: pedicels solitary, 3–6 lines long: sepals lanceolate, acute, margined, 3-nerved, considerably exceeded by the acutish capsule: petals minute or none. — Linnæa, i. 51; Hook. Fl. Bor.-Am. i. 97; Torr. & Gray, Fl. i. 186, 675; Gray, Proc. Am. Acad. viii. 378. *S. borealis*, var. *crispa*, Fenzl ex Torr. & Gray, Fl. i. 675; Torr. Bot. Wilkes Exp. 245. *S. borealis*, var. *apetala*, Regel, Ost-Sib. i. 396 in part. — Mountainous regions of N. Calif. to Alaska.

S. ruscifolia, WILLD. Glabrous: leaves coriaceous, ovate, subcordate, acuminate, somewhat rigid with pungent tip: flowers rather large, terminal, pedunculate: sepals acute. — Willd. in herb. acc. to Schlecht. Berl. Gesell. Nat. Fr., Mag. 1816, 194; Cham. & Schlecht. l. c. i. 50; Regel, Ost-Sib. i. 419. (Siberia, Kamtschatka.)

Var. arctica, REGEL, l. c. i. 420. "Low stems, scarcely an inch in length, sepals obtuse. — On the Melville Islands."

= = Leaves broad, an inch or more in length.

S. littoralis, TORR. Pubescent; stems decumbent, dichotomously branched, 8 inches in height: leaves ovate, rounded at the base, acute or acuminate, about an inch in length, with definite intramarginal veins: flowers rather numerous in the forks of the branches; peduncles becoming horizontal or reflexed: sepals 2½ lines long, acute: petals of nearly equal length, cleft almost to the base: capsule somewhat shorter. — Pacif. R. Rep. iv. 69; Brew. & Wats. Bot. Calif. i. 68. — Coast of Marin Co., Calif.; Punta de los Reyes, *Bigelow;* Dillon's Beach, *Congdon.* In habit much resembling the Old World *S. dichotoma,* L., of which it may well prove a form. It differs, however, in its much more deeply cleft petals.

S. pubera, MICHX. (GREAT CHICKWEED.) Perennial, decumbent, stout for the genus: stems pubescent in lines: leaves elliptic-oblong, finely ciliate, acute or obtusish, ½–1½ inches long, or on the late tall and mostly sterile shoots 3 inches in length: calyx nearly or quite smooth; sepals 3–4½ lines in length: stamens 10: capsule globose, not exceeding the calyx. — Fl. i. 273; Darlingt. Fl. Cest. 274; Torr. & Gray, Fl. i. 183. — Rocky woods, Pennsylvania to Georgia, westward to Tennessee, Kentucky, and Indiana. Professor Britton calls attention to the fact that the teeth of the capsule become circinate-revolute, as in *Cerastium* § *Strephodon.* Miss E. F. Andrews states that the petals are sometimes cleft half their length, in other cases nearly to the base, which is confirmed by specimens.

* * Petals retuse or shortly bifid, divided but ¼–½ the way to the base, commonly considerably exceeding the calyx: species approaching *Arenaria.*

+ Glabrous or nearly so.

S. uniflora, WALT. Weak and slender: stems decumbent or suberect, a foot in length: leaves linear, acute, or the lower lanceolate, gradually narrowed below, mucronate, 8–12 lines in length; the floral much reduced: flowers few, solitary, on elongated slender peduncles: calyx soft in texture; sepals scarcely veined. — Car. 141; Torr. & Gray, Fl. i. 184; Chapm. Fl. 50. *Arenaria glabra,* Ell. Sk. i. 520, not Michx.; Wood, Bot. & Fl. 56. *Alsine Walteri,* Gray, Gen. ii. 34. — Moist meadows, North Carolina to Florida and Alabama, *Winchell;* March to May.

S. MACROPETALA, Torr. & Gray, appears to be only a form of *Arenaria patula,* Michx., a species in which the petals vary from entire to retuse or even bifid.

S. HOLOSTEA, L. Stem sharply 4-angled, 6–18 inches high: leaves narrowly lanceolate, spreading, long-attenuate from near the rounded sessile base, often ciliated, 1¼–3 inches in length, 1-nerved: sepals lance-oblong, thin, nerveless, 4 lines in length, exceeded by the large white petals: styles 3: valves of the capsule at length circinate-revolute. — Spec. i. 422; Reichb. Icon. Fl. Germ. v. t. 223. — Found more or less established at Train's Meadow Road, Long Island, *Ruger;* Poland, Maine, *Miss Furbish.* (Adv. from Europe.)

+ + Glandular-pubescent.

S. dichotoma, L. Stems terete, profusely and dichotomously branched: leaves ovate to ovate-lanceolate, acute or acutish, cordate, spreading, 6–12 lines in length: peduncles 1-flowered, springing from the forks of the branches, considerably exceeding the leaves, commonly deflexed in fruit: sepals lanceolate, acute, usually about equalling the petals. — Spec. 603; Fenzl in Ledeb. Fl. Ross. i. 378. — An Asiatic species of great variability.

Var. Americana, PORTER, in litt. Leaves oval, obtusish: sepals oblong, obtuse, but 1½ lines long, considerably exceeded by the rather narrow white petals. — Collected near Virginia City, Montana, 1871, by *W. B. Platt* on the Hayden Survey, and sent to the Gray Herbarium by Prof. T. C. Porter. A portion of the same material has been kindly examined by Messrs. Batalin, Korshinsky, and Lipsky, who pronounce it a variety or form of *S. dichotoma*, near var. *cordifolia*, Bunge, but with more obtuse leaves and sepals.

S. Jamesii, TORR. Viscid above: stem strongly angled: leaves elongated, lanceolate, attenuate, smooth, 2–4 inches in length, 3–8 lines broad near the closely sessile base: flowers in a leafy terminal panicle: sepals oblong, herbaceous, 2 lines in length. — Ann. Lyc. N. Y. ii. 169 (as *S. Jamesiana*); Pacif. R. Rep. iv. 69; Torr. & Gray, Fl. i. 183; Wats. Bot. King Exp. 38. ?*S. graminea*, James, Cat. 181. — Woodlands and "creek bottoms," Rocky Mts. of Colorado, New Mexico, and Arizona to Northern California and Washington, *Brandegee.*

S. Nuttallii, TORR. & GRAY. Annual, a span high: leaves linear-oblong, obtusish; the upper much reduced but not scarious: flowers in dichotomous racemes; pedicels horizontally spreading, 9 lines in length: corolla 6–8 lines broad. — Fl. i. 183; Fielding, Sert. Pl. t. 18. *Alsine Drummondii*, Fenzl ex Torr. & Gray, l. c. i. 675. *Alsine Nuttallii*, Gray, Gen. ii. 34. — Arkansas, *Nuttall;* Louisiana, *Hale;* Central Texas, *Wright, Lindheimer, Drummond, Hall,* etc.

11. ARENARIA, L. SANDWORT. (*Arena*, sand, a sandy place, from the habitat of several species.) — A composite genus, and, when taken as here in its more comprehensive sense, the largest of the *Alsineæ*. Plants of wide distribution both as regards latitude and altitude, and possessing in consequence much variability in aspect; being either slender annuals or herbaceous perennials of the habit of

Stellaria, or often more densely tufted and occasionally distinctly woody at the base. Leaves sessile or nearly so, either flat and with a well developed blade or more frequently awl-shaped or acerose. Flowers of *Stellaria*, but with petals entire or barely retuse (sometimes more deeply cleft in *A. patula*, Michx.). — Gen. no. 374 in part; Torr. & Gray, Fl. i. 178; Reichb. Icon. Fl. Germ. v. t. 216–219; Benth. & Hook. Gen. i. 150; Wats. Bibl. Index, 94; Hook. & Jackson, Index Kew. i. 178.

§ 1. MŒHRINGIA, L., as amended by Fenzl. Seeds, at least when young, provided at the hilum with a light-colored spongy appendage (strophiole). Habit of *Stellaria*. — Fenzl in Endl. Gen. 968; DC. Prodr. i. 390; Gray, Gen. ii. t. 112.

A. lateriflora, L. Stems terete, weak, often decumbent, puberulent: leaves elliptic-oblong or oval, obtuse or rounded at the apex, thin, puberulent, 5–10 lines long; the veins and edges beneath covered with a fine spreading pubescence: cymes pedunculate and somewhat umbellately few-(1–6-)flowered: sepals ovate, obtuse or scarcely acute, 1¼ lines long, but one third to one half the length of the obovate petals: filaments pubescent. — Spec. 423; Hook. Fl. Bor.-Am. i. 102, t. 36; Torr. & Gray, Fl. i. 182, 675. *A. Pennsylvanica*, Muhl. Ind. Fl. Lanc. 169. *A. buxifolia*, Poir. in Lam. Encycl. vi. 362; Torr. & Gray, Fl. i. 182. *A. Haenkeana*, Bartl. in Presl, Rel. Haenk. ii. 15. *Stellaria biflora*, Pursh, Fl. 317. *Mœhringia lateriflora*, Fenzl, Verbr. Alsin. 18, 38, & Ledeb. Fl. Ross. i. 371; Gray, Gen. ii. 36, t. 112. — New England to New Jersey, Colorado, Oregon, and northward to the Arctic Ocean.

A. macrophylla, HOOK. Stems decumbent, angled, pulverulent-pubescent: leaves lanceolate, acutish to acuminate at both ends, (less commonly elliptic, obtusish.) 1–3 inches in length, glabrous, more or less punctate: peduncles slender, terminal or becoming axillary, 1–5-flowered: sepals ovate-lanceolate, very acuminate, exceeding the petals. — Fl. Bor.-Am. i. 102, t. 37; Torr. & Gray, Fl. i. 182; Torr. Pacif. R. Rep. iv. 69; Gray, Proc. Am. Acad. viii. 378; Greene, Fl. Francis. 125. *Mœhringia macrophylla*, Torr. Bot. Wilkes Exp. 246. — Extending from San Diego (*Orcutt*) northward through California, Oregon, and Washington into British America, and eastward to Isle St. Ignace, Lake Superior, *Wheeler;* April to August. While the essential floral characters remain the same, there is considerable variation in the size, texture, and shape of the leaves.

§ 2. AMMADENIA. Styles 3–5: disk conspicuous, 10-lobed and glanduliferous: capsule globose, somewhat baccate; seeds not strophiolate. — Gmelin, Fl. Sib. iv. 160 (proposed as genus). *Arenaria* § *Ammodenia*, Benth. & Hook. Gen. i. 151. *Honkenya*, Ehrh. Beitr. ii. 180. *Halianthus*, Fries, Fl. Hall. 75. *Adenarium*, Raf. Journ. Phys. 1818, 259. — A single stout fleshy species of maritime habitat, with axillary flowers.

A. peploides, L. Perennial, glabrous: stems a span in height, stout, angled: leaves thick, ovate or obovate, 1-nerved, shortly pointed, clasping at the broad base: sepals ovate-lanceolate, acuminate, 3½ lines in length, about equalling the petals. — Spec. 423; Pursh, Fl. 317. *Alsine peploides*, Crantz, Inst. ii. 406. *Honkenya peploides*, Ehrh. l. c. ii. 181; Torr. & Gray, Fl. i. 176; Fenzl in Ledeb. Fl. Ross. i. 358; Gray, Gen. ii. 32, t. 110. *Adenarium peploides*, Raf. l. c. 259. — Seashores, from New Jersey and Washington State, *Henderson*, northward. (Northern Europe and Asia.) On the Northwest Coast the commoner form is

Var. major, Hook. Taller: leaves longer, often 15 lines in length, oblong or oblanceolate, more pointed and decidedly narrowed to the base. — Fl. Bor.-Am. i. 102. *A. Sitchensis*, Dietr. Syn. Pl. ii. 1565. *Honkenya oblongifolia*, Torr. & Gray, Fl. i. 176. *Honkenya peploides*, var. *oblongifolia*, Fenzl in Ledeb. Fl. Ross. i. 358.

§ 3. Merckia. Styles 3–5; ovary 3–5-celled: capsule large, depressed-globose, somewhat inflated, many-seeded; seeds not strophiolate. — Fisch. ex Cham. & Schlecht. Linnæa, i. 59 (as genus). Fenzl, l. c. i. 359; Pax in Engler & Prantl, Nat. Pflanzenf. iii. 1 b, 84. *Arenaria* § *Merckia*, Benth. & Hook. Gen. i. 151. — A single glandular and slightly fleshy species of the Northwest.

A. physodes, Fisch. Perennial, cespitose; stems weak, decumbent, 3–6 inches in length: leaves ovate, cuspidately pointed, 4–6 lines long: flowers solitary at the summit of the stem or becoming lateral: sepals lance-oblong, acute, 3 lines in length, equalling or slightly exceeding the petals: capsule 4 lines (said to become half an inch) in diameter. — Fisch. in DC. Prodr. i. 413; Wats. Bibl. Index, 97. *Merckia physodes*, Fisch. l. c. i. 59; Hook. l. c. i. 103; Torr. & Gray, Fl. i. 176. *Stellaria ovalifolia*, Hook. l. c. i. 97; Hook. & Arn. Bot. Beech. 122. — Brit. Columbia to N. Alaska; July, August.

§ 4. Euarenaria. Styles normally 3: capsule ovoid, dehiscent by three two-toothed or cleft valves; seeds not strophiolate. — *Arenaria* of many authors, as Fenzl in Ledeb. Fl. Ross. i. 360; Regel, Radde's Reisen in Ost-Sib. i. 334; Pax in Engl. & Prantl, Nat. Pflanzenf iii. 1 b, 84, etc.

* Leaves ovate, elliptic or linear, not acerose.

+ Annuals.

A. **SERPYLLIFOLIA**, L. (THYME-LEAVED SANDWORT.) Annual, finely pubescent, much branched: leaves very short, 2–3½ lines in length, ovate, acute or acuminate, rather distinctly 3–5-nerved, rounded at the base; the lowest only being narrowed to a short petiole: flowers numerous in open leafy cymes; pedicels 1–3 times the length of the ovate-lanceolate acuminate hispidulous sepals: petals small, about two thirds the length of the sepals: capsule flask-shaped. — Spec. 423; Michx. Fl. i. 274; Ell. Sk. i. 518; Torr. & Gray, Fl. i. 182. — Sandy soil, Lower Canada and New England to Florida and to Oregon, Washington, and British Columbia. (Nat. from Europe.)

Var. **TENUIOR**, Koch. More delicate: leaves reduced: flowers smaller in a nearly naked racemose panicle: capsule more oblong.— Synop. 117. *A. leptoclados*, Guss. Fl. Sic. Syn. iii. 824. — Portland, Oregon, *Brandegee*. Suksdorf's specimens from McCloud Lake are somewhat similar. (Europe.)

A. **Benthamii**, FENZL in herb. A slender annual, branched from the base; branches finely pubescent in lines: leaves short, 3–4 lines in length, elliptic-lanceolate, acute and apiculate, often punctate, narrowed to a sessile base. or the lowest to short ciliated petioles; floral leaves much reduced: pedicels filiform, many times exceeding the ovate acuminate glabrous often punctate sepals: seeds dark brown, minutely tuberculate. — Torr. & Gray, Fl. i. 675; Gray, Pl. Wright. ii. 18; Torr. Bot. Mex. Bound. 36. *A. monticola*, Buckley, Proc. Acad. Philad. 1861, 449. — Rocky ground, Texas, *Drummond*, *Wright*, *Thurber*, *Hall*, *Reverchon*; New Mexico, *Thurber*.

+ + Perennials.

A. **ciliata**, L. Minutely glandular-puberulent: stems numerous, slender, terete, leafy, densely matted, or in less exposed situations spreading and ascending, 1–5 inches long, terminally 1–3-flowered: leaves small, ovate-oblong or lance-oblong, scarcely acute, 1–3 lines in length, distinctly ciliate near the cuneate base: peduncles erect, 2–5 lines long: sepals ovate-oblong, obtuse, nerved, 1¼–1½ lines long: petals of similar shape and equal length: stamens 8–10: valves of the capsule rather deeply bifid exceeding the calyx. — Spec. 425; DC. Prodr. i. 411; Fenzl in Ledeb. Fl. Ross. i. 370. (High mountains and arctic regions of Europe.)

Var. (?) **humifusa**, HORNEM. Leaves without ciliation: sepals nerveless. — Hornem. ex Lange, Pl. Grœn. 132. *A. Norvegica*, Gunn, Fl. Norv. ii. 145, t. ix. f. 7–9. *A. humifusa*, Wahlb. Fl. Lap.

129. — Rich soil, British America, Mt. Albert, Gaspe, *Allen, Porter:* Lake Mistassini, *J. M. Macoun*, and what is with scarcely a doubt the same thing at Kicking Horse Lake in the Rocky Mts., *J. Macoun.* (Greenland, N. Europe.)

A. **alsinoides**, Willd. in herb. Minutely pubescent with slightly hooked hairs or smoothish: stems long, procumbent, moderately branched: leaves narrowly elliptic, acute, narrowed below, commonly pseudoverticillate, 8–10 lines long, punctate: flowers axillary, solitary at the nodes: pedicels filiform, elongated, spreading or horizontal. nearly or quite an inch in length: sepals ovate, acute, tuberculate-punctate, $1\frac{3}{4}$ lines long: petals commonly smaller or wanting: seeds smooth and shining. — Schlecht. Berl. Mag. Naturf. Freunde, vii. (1816), 201; Wats. Proc. Am. Acad. xvii. 327. *A. diffusa*, Ell. Sk. i. 519. *A. nemorosa*, HBK. Nov. Gen. et Sp. vi. 35. *A. lanuginosa*, Rohrb. in Fl. Bras. xiv.^{2} 274, t. 63. *Spergulastrum lanuginosum*, Michx. Fl. i. 275. *Micropetalon lanuginosum*, Pers. Syn. i. 509. *Stellaria elongata*, Nutt. Gen. i. 289. *S. lanuginosa*, Torr. & Gray, Fl. i. 187, 675. — Moist shaded ground, North Carolina to Florida and Texas, *Drummond, Hall.* (Mexico and S. Amer.)

A more western form, represented from New Mexico by Fendler's 58 and 62 and Wright's 864, has slightly firmer stems, more numerous sub-paniculate flowers, and leaves less narrowed at the base. In all these respects it shows a transition to the following.

A. **saxosa**, Gray. Finely puberulent but green: stems many, spreading from a rather stout root, decumbent or creeping at the base, 2 inches to a foot long: leaves numerous, opposite, not fascicled or pseudoverticillate (sometimes crowded), slightly fleshy, lance-oblong, acute, mucronate, 2–9 lines long, sessile by a scarcely narrowed base: flowers terminal and subsolitary on short simple peduncles or in stouter individuals numerous and more or less paniculate: petals almost or quite equalling the ovate-lanceolate sharply acuminate slightly fleshy sepals. — Pl. Wright. ii. 18; Walp. Ann. iv. 258. *Mœhringia umbrosa*, Gray Pl. Fendl. 13, & Pl. Wright. ii. 18, not Fenzl. — Colorado, *Brandegee, Hooker & Gray:* Guadalupe Mts., Texas, *Havard;* New Mexico, *Fendler, Wright;* Arizona, *Rothrock, Lemmon, Jones, Rusby.* (Lower California, *Orcutt.*) A species of wide range, occurring alike in rocky subalpine regions and much lower upon sandy banks, accordingly varying much in height and diffuseness of branching. The type is a condensed few-flowered form.

Var. **cinerascens.** Somewhat more rigid, and grayish throughout with a fine pubescence: leaves pungent. — Huachuca Mts., Arizona, *J. G. Lemmon.* (Herb. Columbia Coll.)

* * Leaves very narrowly linear, commonly acerose and often rigid and pungent; western species.

+– Sepals broadly ovate, obtusish, sometimes apiculate: flowers not densely aggregated.

A. capillaris, Poir. Leaves chiefly grouped at the base in fascicles upon a multicipital caudex, ½–2½ inches long, somewhat pungent, little spreading; the cauline few pairs, much reduced: stems 4–8 inches in height: petals obovate, considerably exceeding the short obtuse sepals. — Poir. in Lam. Encycl. vi. 380; Regel, Ost-Sib. i. 366. *Alsine nardifolia*, Anderson, Cat. 118. The typical glabrous form with straight leaves is comparatively rare in America but occasionally occurs with var. NARDIFOLIA, Regel, l. c. i. 372, which is glabrous with curved leaves (*A. nardifolia*, Ledeb. Fl. Alt. ii. 166, & Icon. Fl. Ross. 6; Hook. Fl. Bor.-Am. i. 98, t. 32), and the more common form var. FORMOSA, Regel, l. c. i. 371, which has the stem and inflorescence glandular. (*A. formosa*, Fischer in DC. Prodr. i. 402; Hook. f. Arc. Pl. 287, 322; Torr. Bot. Wilkes Exp. 243.) — Central California to Utah, Montana, and British Columbia. (Asia.)

A. ursina. Root stout, ligneous: caudex very densely multicipital and bearing very close fascicles or rosettes of very short filiform-linear thickish glaucous glandular-ciliolate white-punctate apiculate leaves (but 2–3 lines in length): stems few, erect, branched, slender, finely glandular-pubescent, 1½–3 inches high, bearing one or two pairs of short distant spreading and rather rigid leaves: sepals nerveless: petals white, oblong, slightly emarginate: alternate filaments glanduliferous at the base: mature capsule considerably exceeding the calyx, about 6-seeded. — Dry hills, Bear Valley, San Bernardino Mts., *S. B. & W. F. Parish*, August, 1882. This species has much the habit of *A. compacta*, Coville, but much more obtuse sepals; it is most nearly related to *A. capillaris*, Poir., but differs in its condensed habit and in a waxy punctation of the leaves.

A. aculeata, Wats. Leaves grouped chiefly in fascicles at the summits of a multicipital caudex, decidedly glaucous, rigid and pungent and with age strongly spreading, 6–12 lines in length; cauline leaves few, shorter: stems simple up to the few-flowered cymes, 4–6 inches high: petals rather narrow, elliptic-oblanceolate, obtuse, 1½–2 times as long as the sepals. — Bot. King Exp. 40, & Bibl. Index, 94. — Chiefly in mountainous districts from Oregon (*Nevius*, *Cusick*, *Howell*) to N. Nevada (*Watson*), S. Utah, and Arizona (?). The sepals are variable and become more acute in the southern form, which is more difficult to distinguish from those varieties of *A. congesta* which have an open inflorescence.

+ + Sepals ovate, or ovate-lanceolate, acuminate, shorter than the petals (except in *A. macradenia*, var. *Parishiorum*).

A. compacta, Coville. Root thick, ligneous: caudex much branched and bearing very closely tufted rosulately spreading subulate glaucous leaves; the latter not exceeding 2 lines in length, minutely glandular, ciliate: stems slender, an inch or more in height, simple or sparingly branched, almost naked, the cauline leaves being few and much reduced: flowers terminal on the branches: sepals 1½ lines long, scarious-margined, thickened in the middle, attenuate. — Proc. Biol. Soc. Wash. vii. 67; Contrib. U. S. Nat. Herb. iv. 70, t. v. — Mountains of Tulare Co., Calif., *Coville*, August, 1891.

A. congesta, Nutt. Smooth, or more rarely glandular-pubescent: stems slender, simple, 5–14 inches high, numerous, springing from a matted non-ligneous caudex: basal leaves gramineous-setaceous, ½–3 inches long, ciliolate-serrate near the base: cauline leaves rather distant, gradually reduced: flowers sessile or shortly and unequally pedicelled in 1–3 dense heads (subtended by 1–several pairs of scarious-margined bracts): sepals carinate, obscurely 3-nerved, membranous-margined, 2 lines long, considerably exceeded by the narrowly oblong petals: stigmas not strictly capitate. — Nutt. in Torr. & Gray, Fl. i. 178; Torr. Frem. Rep. 87; Wats. Bot. King Exp. 39; Porter & Coulter, Fl. Col. 13; Brew. & Wats. Bot. Calif. i. 69; Greene, Fl. Francis. 123 (excl. syn.); Mrs. Brandegee, Zoe, ii. 161. — Rocky Mts. of Colorado and Wyoming to the Yosemite (acc. *Mrs. Brandegee*) and northward to Washington, *Suksdorf.*

Var. suffrutescens. Caudex sometimes, perhaps always, very ligneous; its branches becoming 2–3 lines in diameter, bearing fascicled sub-equal leaves (an inch or less in length): flowers somewhat smaller (sepals 1½ lines long) in spherical capitate umbels: pedicels slender, 2–3 times as long as the calyx: stigmas capitate. — *Brewerina suffrutescens*, Gray, Proc. Am. Acad. viii. 620, under *A. congesta;* Brew. & Wats. Bot. Calif. i. 69; Wats. Bibl. Index, 95; Greene, Fl. Francis. 123. — California, Cisco, *Bolander & Kellogg;* Emigrant Gap, *Jones;* Tulare Co., *Coville & Funston*, 1504. A form too well marked in its foliage, ligneous caudex, and allium-like inflorescence to be united with the typical *A. congesta*, yet appearing to intergrade with it. One of the transitional forms has been collected in Sierra Valley by *Lemmon.*

Var. subcongesta, Wats. Caudex more or less ligneous, stems smooth, glandular or pulverulent-pubescent, often knotted with enlarged nodes: flowers as in the type, but borne in more or less expanded dichotomous cymes: leaves varying greatly in length and texture. — Bot. Calif. i. 69; Bibl. Index, 454. *A. Fendleri*, var. *subcongesta*, Wats. Bot. King Exp. 40, & Pl. Wheeler, 6; Porter & Coulter, Fl. Col. 13; Rothr. Enum. Pl. Col. 35. *A. Fendleri*, var. *glabrescens*, Wats. Bot. King Exp. 40, & Bibl. Index, 95, differs only in its still looser inflorescence, and should doubtless be referred hither. — Rocky Mts. of Colorado and Arizona, *Newberry*, to British America, Cypress Hills, *Macoun*, westward to Oregon, *Howell*, and California, Sierra Co., *Lemmon*, Donner Pass, *Torrey*. These puzzling and inconstant forms are intermediate between this species and *A. capillaris*, *A. Fendleri*, and *A. macradenia*. From the last they scarcely differ save in their smaller flowers and slightly in the form of the petals.

A. macradenia, Wats. (revised). Glabrous or nearly so: rootstock more or less ligneous, extensively and irregularly branched: stems stout for the genus, 6–15 inches high, knotted with the enlarged nodes: leaves chiefly cauline, glaucous, rigid, pungent, ½–2 inches long: flowers larger than in the related species, in an open cyme: sepals fleshy subcarinate, 2½–2¾ lines long, with membranous margins: petals considerably exserted, obovate or oblong with an obtusish sometimes auricled base: stamineal glands moderately developed: stigmas subcapitate. — Proc. Am. Acad. xvii. 367 in part. — S. California, Mohave River, *Palmer*, 41; Antelope Valley, *Oliver;* S. Utah, *Parry*, 20, *Palmer;* Arizona, *Palmer;* Mt. Agassiz, *Lemmon*. These plants with their exserted petals and ligneous caudices best represent Dr. Watson's species as described, Palmer's no. 41 being the first mentioned type.

Var. (?) Parishiorum. Smooth or minutely glandular-pubescent: caudex scarcely ligneous, densely multicipital: stems slender; nodes not conspicuously enlarged: leaves chiefly basal: petals narrowed at the base, shorter than or barely equalling the sepals, the latter fully 3 lines in length: stamineal glands very large. — *A. macradenia*, Wats. l. c. xvii. 367 in part. — Common on mountains bordering on the Mojave Desert, *S. B. & W. F. Parish*, no. 1330.

+ + + Sepals lanceolate to lance-linear, attenuate, equalling or exceeding the petals.

++ Flowers cymose, not densely aggregated.

A. Fendleri, Gray. Rather pale and glaucous, finely glandular-pubescent above: stems numerous, erect, leafly, 4–15 inches high, closely aggregated upon the summit of a thick root: basal leaves setaceous, gramineous, ciliolate or quite smooth, 2–4 inches in length, somewhat pungent; the cauline gradually shorter, connate and sheathing at the base: the internodes an inch or two long: inflorescence dichotomous, few to many flowered: sepals attenuate, glandular, nearly equalling the obovate petals (2½–3 lines in length): capsule commonly a fourth shorter. — Pl. Fendl. 13; Torr. Pacif. R. Rep. iv. 69; Wats. Bot. King Exp. 40, exclusive of var. *glabrescens;* Porter & Coulter, Fl. Col. 13. — Chiefly in the Rocky Mts., but sometimes among the sage-brush of the plains. Nebraska, *Engelmann;* Colorado to New Mexico, *G. R. Vasey;* San Francisco Mts., Arizona. *Lemmon;* Los Angeles, Cal., *Nevin.* The var. DIFFUSA of Prof. Porter's Fl. Col. is a greener form from the Rocky Mts. of Colorado and Wyoming with a more lax and spreading inflorescence and often although not always larger flowers. It intergrades with the type, so that in herbarium specimens at least its separation is often unsatisfactory. A form collected by Prof. Porter in the Garden of the Gods, and possessing very small flowers (sepals 1¼–1½ lines in length) upon curved and spreading branches, is perhaps equally worthy of varietal distinction.

+ + Flowers densely fascicled at the summit of the stem.

A. **Franklinii**, DOUGL. Caudex of numerous procumbent more or less elongated branches, covered with somewhat persistent dried leaves: stems quite smooth, erect, simple, 3–5 inches high, somewhat rigid but fragile, bearing 3–6 pairs of narrowly subulate pungent spreading smooth or ciliolate and minutely scabrous leaves (5–9 lines long): cymes dense, sub-involucrate: sepals elongated, attenuate, pungent with slightly spreading tips, 1-nerved, 4–6 lines long, distinctly exceeding the petals. — Hook. Fl. Bor.-Am. i. 101, t. 35; Torr. & Gray, Fl. i. 178; Torr. Bot. Wilkes Exp. 244. — Sandy soil, Oregon, *Douglas, Lyall, Howell, Nevius, Cusick;* Washington, *Suksdorf.* Specimens collected by *Douglas* at source of the Missouri may well have been the next species.

A. **Hookeri**, NUTT. Caudex densely multicipital: stems 1–4 inches high, pubescent: leaves shorter than in the last: flowers smaller and petals about equalling or slightly exceeding the sepals. — Nutt. in Torr. & Gray, Fl. i. 178. *A. Franklinii*, var. *minor*, Hook. & Arn. Bot. Beech. 326; Wats. Bibl. Index, 95; Coulter, Man. Rocky Mt. Bot. 35. *A. Franklinii*, Engelm. Trans. Am. Phil. Soc. n. ser. xii. 186; Coulter, l. c. 35 in great part; Hook. & Jackson, Index Kew. 179. — Rocky Mts., lat. 40°, *Nuttall;* Colorado, *Vasey;* Wyoming, *Hayden, Parry, Porter, Greene, Sheldon;* Plains of Green River, *Gray;* Nebraska, *Rydberg, Webber;* Montana, *Tweedy.* This species with much the habit of the preceding differs in its much denser caudex and constantly pubescent stem, as well as in the differences indicated. The stem is terete even in a dried state, while the stems of *A. Franklinii* in drying become furrowed and angulate, as though slightly fleshy.

§ 5. ALSINE, Wahlenberg (as genus, not Linn.). Capsule ovoid, 3-valved; valves entire; seeds not strophiolate: matted perennials or delicate annuals, usually with narrow linear subulate or acerose leaves. — Fl. Lapp. 127; Fenzl in Ledeb. Fl. Ross. i. 341; Regel, Radde's Reisen in Ost-Sib. i. 337; Pax in Engl. & Prantl, Nat. Pflanzenf. iii. 1 b, 82.

* Palustrine perennial with weak elongated stems, narrow linear or lance-linear leaves and axillary long-peduncled flowers.

A. paludicola. Glabrous, flaccid: stems several, subsimple, procumbent, rooting at the lower joints, sulcate, shining, leafy throughout: leaves uniform, flat, 1-nerved, acute, spreading, ¾–1½ inches long, 1–3 lines in breadth, often punctate, somewhat connate, slightly scabrous upon the margins: peduncles solitary in the axils, 1–2 inches long, spreading or somewhat deflexed: sepals nerveless, not at all indurated, acutish about half the length of the obovate petals. — *A. palustris*, Wats. (not Gay). Bot. Calif. i. 70, & Bibl. Index, 97; Greene, Fl. Francis. 124; Mrs. Brandegee, Zoe, ii. 341. *Alsine palustris*, Kellogg, Proc. Calif. Acad. iii. 61. — Abundant in swamps about Fort Point near San Francisco, *Bolander*, *Kellogg & Harford;* also in swamps near San Bernardino, *Parish Bros.;* May to August.

* * Terrestrial annuals of the Atlantic Slope and Alleghany Mountains, rarely extending to the interior in the Southern States, essentially glabrous: sepals obtuse, soft in texture, scarcely or not at all nerved.

A. Grœnlandica, SPRENG. Somewhat fleshy: root at first simple, later of many delicate fibres: stems few to many, decumbent or erect, subsimple, 2–8 inches long, bearing 1–5 flowers: leaves linear, obtuse, 1½–7 lines long, at first in a dense, more or less rosulate cluster at the base; the cauline 2–4 pairs: sepals broadly ovate, 1½–2 lines in length: petals obovate, about twice as long, entire or notched: capsule subglobose to oblong, more or less contracted to a point. — Syst. ii. 402; Torr. & Gray, Fl. i. 180; Torr. Fl. N. Y. i. 95, t. 15. *A. glabra*, Torr. Fl. U. S. 455, not Michx.; Bigel. Fl. Bost. ed. 2, 180. *Alsine Grœnlandica*, Gray, Man. ed. 2, 58. *Stellaria Grœnlandica*, Retz. Fl. Scand. ed. 2, 107; Vahl, Fl. Dan. vii. t. 1210. ? *S. Labradorica*, Schrank, Pfl. Lab. 24; Meyer, Pl. Lab. 93. — Rocky soil, chiefly but not always at higher altitudes, Greenland to the coast of Maine, Bath, *Gambel;* Bar Harbor, *Rand;* also at Middletown, Conn., *Osborn*, *Wright;* locally abundant in the White, Green, Adirondack, Catskill, and Shawangunk Mts.; reported from Kittatinny Mts. of N. W. New Jersey (*Britton*, Bull. Torr. Club, xi. 128), and recently found in the mountains of Pennsylvania (according to *Prof. Porter*), of S. Virginia (*Small & Heller*), and in N. Carolina (*Small*), where it had passed as a form of *A. glabra*, Michx., having been previously collected on Roan Mountain by *Gray & Carey*, *Smith*, and *Scribner*.*

A. **glabra**, Michx. Glabrous, loosely matted, many-stemmed: stems weak, slender, suberect, very leafy, 6–12 inches high: leaves narrowly linear, spreading, thin, nerveless, equalling or exceeding the internodes: peduncles filiform, elongated, spreading, 1-flowered: corolla rather broad, considerably exceeding the calyx: sepals ovate-oblong, obtuse, nerveless, 1½ lines in length, somewhat exceeded by the ovoid capsule. — Fl. i. 274; Torr. & Gray, Fl. i. 180 in part. *Alsine glabra*, Gray, Man. ed. 2, 58; Chapm. Fl. 49. — On rocks in mountains of N. Carolina, *Michaux;* Table Mountain, *Gray*; Table Rock, S. Carolina, *Vasey;* Stone Mt., Ga., *Gray;* De Kalb Co., Ga., *Small;* also in the Arroyo of Lamben, near the Mexican boundary, *Parry*.

A. **brevifolia**, Nutt. Glabrous: stems erect, filiform, 2–5 inches high, with spreading branches: leaves linear or lance-linear obtuse, nerveless, slightly fleshy, 1–4 lines long, commonly much shorter than internodes: sepals ovate-oblong, obtuse, only a line in length, with a distinct thin white margin: petals rather conspicuous, obovate, 2½–3½ lines in length, widely spreading: capsule ovoid, acuminate, a third longer than the calyx; valves ovate, acuminately narrowed almost to the tip. — Nutt. in Torr. & Gray, Fl. i. 180. *Alsine brevifolia*, Chapm. Fl. 49. — On rocks, Georgia, Tatnal County, *Nuttall;* Stone Mountain, *Canby*, *Gray*, *Small;* April, May. Apparently the most rare and local eastern species.

* * * Terrestrial annuals of the Pacific Slope: sepals neither indurated nor very strongly nerved.

+ Seeds much flattened, and margined.

A. **Douglasii**, Torr. & Gray. Thinly glandular-pubescent and somewhat viscid, or nearly glabrous: stems much branched, 2–15 inches high: leaves attenuate to filiform points: peduncles filiform: flowers numerous, larger than in the related species, 4–5 lines in diameter: sepals ovate, thin-margined, obscurely or more or less distinctly ribbed: petals obovate, conspicuous: capsule subglobose; the valves rounded at the apex; seeds large, smooth, or with fine radiate striation, reniform, broadly margined. — Fl. i. 674; Durand, Pl. Pratt. 83; Brew. & Wats. Bot. Calif. i. 69; Greene, Fl. Francis. 124. *A. verna*, *β*, Hook. & Arn. Bot. Beech. 325. *Greniera Douglasii*, Gay, Ann. Sci. Nat. ser. 3, iv. 27. *Alsine tenella*, Torr. Bot. Mex. Bound. 36 (ex char. et hab.). — Barren hillsides and grassy slopes, S. Arizona, *Palmer*, and S. California to Oregon, *Howell*, *Henderson;* some smaller flowered specimens with seeds of *A. Douglasii* have been collected by *Thurber* in San Diego, Calif.

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* For further discussion of this species see page 328.

+ + Seeds not flattened nor thin-margined.

A. Howellii, Wats. Finely glandular-pubescent: stem terete, purple, diffusely branched, more than a foot high: leaves rather thick, obtuse, 4–7 lines in length; the floral much reduced: flowers 2½–3 lines in diameter: petals oblong, little exceeding the ovate glandular nerveless sepals: capsule ovoid, pointed; valves narrowed to an acutish apex; seeds dark, slightly tuberculate-crested. — Proc. Am. Acad. xx. 354.

A. Californica, Brewer. Smooth: the delicate filiform stems branching from the base, erect, 2–4 inches in height: leaves very short, slightly fleshy, 1–2 lines in length, obtuse: flowers 4 lines in diameter: petals oblong, about twice the length of the ovate-oblong nerveless or inconspicuously ribbed sepals: seeds small, finely roughened. — Brewer in Boland. Cat. 6; Brew. & Wats. Bot. Calif. i. 69; Greene. Fl. Francis. 124. *A. brevifolia*, var. (?) *Californica*, Gray, Proc. Calif. Acad. iii. 101. — Dry hills, sandy soil. Central Calif. to Grant's Pass, Oregon, *Howell.*

A. pusilla, Wats. Smooth, very diminutive, 1½–2 inches high: stems purplish, filiform, branched from the base: leaves obtusish, but 1–2 lines in length: sepals not so strongly nerved as in the preceding, 1–1¼ lines in length: petals minute or wanting: seeds minute, smooth. — Proc. Am. Acad. xvii. 367. *A. Californica* of Bot. Calif. (in part). — Plains about Yreka, Calif. (*Greene*), to the Dalles of the Columbia (*Howell Bros.*), and White Salmon, Wash. (*Suksdorf*).

* * * * Annuals or slender-stemmed loosely matted perennials, 5–15 inches in height: sepals lanceolate, acuminate or attenuate, strongly 3–5-nerved.

+ Puberulent.

A. tenella, Nutt. Finely glandular-pubescent: stems very slender, dichotomously branched almost from the base, 3–8 inches in height: leaves attenuate from a connate prominently ribbed base to a filiform often curved apex, 3–5 lines long; the uppermost considerably reduced: pedicels filiform, several times as long as the strongly

3-ribbed sepals; the latter equalled or more or less exceeded by the oblong petals: valves of ovoid capsule exceeding the sepals; seeds small, margined with a fine muriculate crest (under a strong lens). — Nutt. in Torr. & Gray, Fl. i. 179; Eaton & Wright, N. A. Bot. 133 (excl. Arkansas spec.); Macoun. Bot. Gaz. xvi. 286. *A. tenuifolia*, var. *Americana*, Fenzl ex Torr. & Gray, Fl. i. 674. *Greniera tenella*, Gay, Ann. Sci. Nat., ser. 3, iv. 27. *Alsine tenella*, Torr. Bot. Wilkes Exp. 243. — Rocky places, flowering in midsummer; Oregon, *Nuttall*, *Tolmie*, *Hall*, *Howell*, to British Columbia, Kamloops acc. to *Macoun*; Nanaimo, *Miss Cooley*. Like *A. Grœnlandica* of the Eastern States, this species seems to occur either in mats or in a segregated state. In the former condition it considerably resembles *A. stricta*, Michx., but is to be distinguished by its small flowers and puberulent inflorescence. It differs from *A. patula* in its broadly elliptic petals not at all truncate or retuse.

A. patula, Michx. Stem diffusely branched, 2 inches to a foot in height, often almost filiform: leaves spreading, slightly fleshy: inflorescence dichotomous; pedicels filiform, spreading: sepals lanceolate, attenuate, with 3–5 prominent converging nerves, slightly indurated, a little over 2 lines in length, usually minutely glandular: petals twice as long, entire or retuse, obcordate: the obtuse valves of the capsule about equalling the calyx; seeds black, minutely roughened. — Fl. i. 273; Torr. & Gray, Fl. i. 180; Gray, Man. ed. 5, 91; Hill, Bull. Torr. Club, xvii. 172; Macmillan, Bot. Gaz. xv. 332. *A. Pitcheri*, Nutt., and (?) *A. tenella*, Nutt. in Torr. & Gray, l. c., so far as Arkansas plants are concerned. *Alsine microsperma*, Fenzl ex Torr. & Gray, Fl. i. 674. *A. patula*, Gray, Man. ed. 2, 58; Chapm. Fl. 49. *A. Pitcheri*, Wood, Class-Book, 260; Chapm. Fl. (Suppl.) 608. *Stellaria macropetala*, Torr. & Gray, Fl. i. 184 (*Alsine macropetala*, Gray, Gen. ii. 34), differing only in the slightly more deeply divided petals, which are themselves more or less variable, must be referred hither, where its identity of habit and calyx clearly indicates its affinity to be. — Kentucky to Alabama (*Peters*, *Mohr*) and Texas (*Drummond*, *Meyer*, *Buckley*), northward to Chicago (*Babcock*, *Hill*) and Cass Co., Minnesota (acc. to *Macmillan*). The leaves of this species are variable, commonly narrowly linear or filiform, 4–7 lines in length, but they occasionally become 1½ inches long and a line wide.

+ + Glabrous.

A. stricta, Michx. Smooth, loosely matted: stems very numerous, slender, ascending, 3–15 inches high, leafy nearly to the middle: leaves subulate-setaceous, conspicuously fascicled in the axils: inflorescence a loosely forked cymose panicle: petals narrowly obovate, nearly twice the length of the somewhat rigid acuminate prominently 3-ribbed sepals: capsule about equalling or exceeding the calyx. — Fl. i. 274; Ell. Sk. i. 521; Hook, Fl. Bor.-Am. i. 99, t. 33 (including both var. *α*, a weak boreal few-flowered form with erect leaves, and var. *β*, the common form with spreading leaves); Torr. & Gray, Fl. i. 179, var. *β*; Britton, Mem. Torr. Club, ii. 37. ? *A. setacea*, Muhl. Ind. Fl. Lanc. 169. *A. Michauxii*, Hook. f. Arc. Pl. 287, 322. *Alsine Michauxii*, Fenzl, Verbr. Alsin. 18; Regel, Ost-Sib. i. 351, t. 8, f. 1–5. — Rocky and gravelly soil, Vermont to S. Carolina, westward to Minnesota.

Var. Texana. More rigid, stems fewer, 3–7 inches high, strongly enlarged at the nodes: leaves very short, conspicuously connate; the fascicled ones but 1–2 lines long: flowers in a small rather dense cyme: sepals almost cartilaginous, very strongly 3-nerved, appearing attenuate through the infolding of their margins. — ? *A. stricta*, var. *α*, Torr. & Gray, Fl. i. 179. — Rocky Hills, Texas; along the Canadian River, *Gordon*, April, 1848; *Bigelow*, August, 1853; Dallas, *Hall*, July, 1872: Comanche Peak, *Reverchon*. 1881; Arkansas, *Leavenworth;* False Washita, Ind. Ter., *Palmer;* Kansas, Norton, *Smith*. Owing to its definite and limited geographic range this variety may, as Dr. Britton suggests, prove worthy of specific rank. The characters, however, are not very definite, and a specimen from Potosi, Mo. (*F. Peck*) exactly connects it with the type. While the description of Torrey and Gray's var. *α*, cited above, ill accords with the present plant and rather suggests that these authors intended their var. *α* to be equivalent to the var. *α* of Hooker, as their var. *β* was of his var. *β*, yet in the Columbia Herbarium there are specimens of the southwestern plant labelled in Torrey's hand as var. *α*. If the Texan plant was the var. *α* of Torrey and Gray, it need scarcely be said that it could not have been the typical form of Michaux's species, as it was doubtless intended to be.

* * * * * Perennials, closely matted or tufted, 1–6 inches in height: sepals acuminate, but not strongly nerved, except in *A. verna*.

A. verna, L. Rather closely tufted: stems numerous, slender, ascending or erect, smooth, 1–5 inches high, 1 to 3 (or more) flowered; the upper internodes commonly considerably exceeding the leaves: leaves linear-subulate, flat, rather strongly 3-nerved, usually erect and never squarrose: peduncles filiform: sepals ovate-oblong, acutish to acuminate, strongly 3-nerved, $1\frac{1}{2}$–$1\frac{3}{4}$ lines long, exceeding the obovate or oblanceolate obtusish petals: capsule somewhat surpassing the calyx. — Mant. i. 72; Seringe in DC. Prodr. i. 405; Hook. Fl. Bor.-Am. i. 99; Torr. & Gray, Fl. i. 181. *A. juniperina*, Pursh, Fl. 318; Hook. Fl. Bor.-Am. i. 98; Torr. & Gray, Fl. i. 179, 674. *Alsine verna*, Bartl. Beitr. ii. 63. — A widely distributed species with numerous but ill defined varieties. The smooth typical form appears to be common in the Rocky Mts. of British America (*Macoun*), and has been found on Mt. Albert, Lower Can. (*Allen*). A far more frequent form is

Var. hirta, Wats. Finely glandular-puberulent upon stems, peduncles, and calyx: leaves nearly or quite smooth. — Bot. King Exp. 41; Porter & Coulter, Fl. Col. 14; Rothr. Enum. Pl. Col. 35. *A. hirta*, Wormsk. Fl. Dan. x. t. 1646. *A. propinqua*, Richardson in Frankl. Journ. 738. *Alsine verna*, var. *hirta*, Fenzl in Ledeb. Fl. Ross. i. 349. *A. rubella*, var. *hirta*. Lange, Pl. Grœnl. 132. *A. propinqua*, Lange, Fl. Dan. xvii. t. 2903. *A. hirta*, Warming, Bot. Foren. Festskr. 1890, 229. — From Greenland to Alaska, southward to Smugglers' Notch, Vt. (*Pringle*), and along the Rocky Mts. to Arizona (*Lemmon*); also in the San Bernardino Mts. (*Wright*).

Var. rubella, Hook. f. Depauperate, minutely glandular-puberulent or very rarely smooth: peduncles and sepals purplish tinged, the latter less strongly nerved. — Journ. Linn. Soc. v. 82. *A. Gieseckii*, Hornem. Fl. Dan. ix. t. 1518. *A. hirta*, var. *glabrata*, Cham. & Schlecht. Linnæa, i. 56. *Alsine rubella*, Schrenk in Fenzl, l. c. i. 349. *A. verna*, var. *glacialis*, Fenzl fide Wats. Bibl. Index, 99. — Occurring with and often scarcely to be distinguished from the preceding.

A. Rossii, Richardson. Dwarf and closely tufted, glabrous: leaves crowded, narrowly linear, 3-edged, obtusish, slightly fleshy: stems many, ½–1½ inches long, filiform, usually ending in a solitary peduncle, more rarely branched and several-flowered: sepals attenuate, slightly fleshy, not at all rigid and scarcely or not at all ribbed, 1–1½ lines long: petals oblong, nearly equalling the calyx, often minute or none: capsule shorter than the calyx. — Richardson in Frankl. Journ. 738; R. Br. in Parry's 1st Voy. App. 272; Hook. Fl. Bor.-Am. i. 100; Torr. & Gray, Fl. i. 181; Porter & Coulter, Fl. Col. 14. *A. elegans*, Cham. & Schlecht. Linnæa, i. 57. *A. stricta*, Wats. Bibl. Index, 98, in part, not of Michaux nor Wahlenberg's *Alsine stricta* of the Old World, which is surely distinct. *Alsine Rossii*, Fenzl, Verbr. Alsin. 18. — Mountains of Colorado, *Hall & Harbour*, *Coulter*, *Wolf*; Wyoming, *Parry*; British America, *Bourgeau*, to Arctic America.

A. Nuttalli, Pax. Glandular-puberulent or tomentulose throughout: root single, vertical, rather stout: stems many, loosely matted and much branched near the base; branches ascending or erect, leafy:

leaves subulate-acerose, rigid, pungent, tending to be squarrosely spreading, connate, 3–4 lines long: flowers usually numerous in spreading cymes, rarely subsolitary: sepals attenuate, acuminate, often purplish, not strongly nerved, 2–2½ lines long, exceeding the more or less pointed petals and ovoid capsule. — Pax in Engler, Jahresb. xviii. 30. *A. pungens*, Nutt. in Torr. & Gray, Fl. i. 179 (not of Clem.); Wats. Bot. King Exp. 40. — Rocky Mts. from Wyoming to S. British America, westward in mountainous regions to Washington and S. California.

Var. **gracilis.** Sepals narrow, elongated and still more attenuate, 2½–3 lines long: leaves less rigid, scarcely spreading or pungent. — *A. pungens*, var. *gracilis*, Gray in herb. — California Mts. above Big Tree Grove, *Bolander*, 4976; Long Meadow, Tulare Co., *Palmer*, *Coville & Funston*. Intergrading with the typical form.

* * * * * * Densely cespitose perennials with acicular or awl-shaped leaves: sepals oblong, or linear-oblong, very obtuse.

+ Alpine, boreal or arctic species.

++ Petals oblong or narrowly obovate.

A. Sajanensis, Willd. Cespitose: stems finely but rather densely glandular-hirsute, decumbent, very leafy below and with age sheathed at the base with the dried persistent leaves; the upper more or less erect portion of the stems ½–2½ inches in length, bearing two or three pairs of short and rather distant more or less puberulent leaves, and terminating in 1 to 3 flowers; lower leaves linear, obtusish, rather rigid, erect, 2–3½ lines long, quite glabrous or ciliolate, less commonly glandular-pubescent, straight: segments of the calyx linear-oblong, 1–3-ribbed, glandular-pubescent, 2 lines in length: petals spatulate, equalling or half exceeding the sepals, rarely nearly twice as long (but narrower than in *A. arctica*): valves of the capsule linear-oblong, obtuse, often considerably exceeding the calyx. — Willd. in Schlecht. Berl. Mag. Natf. 1816, 200; DC. Prodr. i. 408. *A. thymifolia*, James, Cat. 181. *A. obtusa*, Torr. Ann. N. Y. Lyc. ii. 170. *A. biflora*, Wats. Bibl. Index, 94, not of Linn. *A. arctica*, and vars. of various authors, not of Stev. *Stellaria biflora*, L. Spec. 422. *Alsine biflora*, Wahlenb. Fl. Lappon. 128; Fenzl in Ledeb. Fl. Ross. i. 355. — Mt. Albert, Lower Can., *Allen*, *Macoun*, to Labrador and Behring Strait, southward to Oregon, *Cusick*, and along the Rocky Mountains to New Mexico, *Parry*, and Arizona, *Lemmon*. (Greenland and Siberia.) A common species widely distributed in alpine and arctic regions of the Old and New World. Its confluent varieties and forms seem largely due to individual environment. The following only need be mentioned: var. RIGIDULA (*Alsine biflora*, var. *rigidula*, Fenzl, l. c.), with leaves erect, firm in texture and rather closely imbricated; and var. CARNOSULA (*Alsine biflora*, var. *carnosula*, Fenzl, l. c.), more flaccid, with leaves spreading and slightly fleshy.

? **A. laricifolia**, L. Slightly woody and much branched at the base: stems clothed with linear acicular secund ciliolate-denticulate leaves: fertile branches erect, simple, 4–7 inches in height, 2–5-flowered: sepals 3½ lines in length, linear-oblong, 3-nerved: petals oblong or narrowly obovate, entire, twice as long as the calyx. — Spec. 424. — An alpine European species at various times reported from Alaska but still somewhat doubtful. Plants recently collected upon the Porcupine River by *J. H. Turner* certainly possess much resemblance to the European plant, but differ in their shorter sepals and less leafy stems. It is not unlikely that they may prove merely a tall and long-petalled form of the preceding polymorphous species.

++ ++ Petals broadly obovate, much exceeding the calyx: Alaskan.

A. arctica, Stev. Stems 1–3 inches long, glandular-pubescent: lower leaves narrow, linear, obtuse, slightly fleshy, crowded upon the bases of the stems, nearly or quite glabrous, sometimes slightly ciliated near the base, half a line in breadth; the upper leaves a little broader, and more or less distant: flowers solitary, terminal upon slender glandular-pubescent peduncles, 5–7 lines in diameter: capsule 3½–4 lines long, considerably exceeding the sepals: seeds minutely roughened and slightly crested. — Stev. in DC. Prodr. i. 404; Cham. & Schlecht. Linnæa, i. 54; Hook. Fl. Bor.-Am. i. 100 (excl. vars.); Torr. & Gray, Fl. i. 181 in part. *Alsine arctica*, Fenzl, Verbreit. Alsin. 18, & Ledeb. Fl. Ross. i. 355; Regel, Ost-Sib. i. 338, 346 (excl. var. breviscapa). — Western and Northern Alaska and adjacent islands.

A. macrocarpa, Pursh. Stems 2–4 inches long, covered except near the ends with the densely imbricated lance-linear obtuse conspicuously ciliated leaves; the latter ¾ of a line broad: flowers solitary, terminal, often exceeding ½ inch in diameter: valves of the mature capsule fully 6 lines in length; seeds slightly margined. — Fl. 318; Cham. & Schlecht. Linnæa, i. 55; Hook. Fl. Bor.-Am. i. 101; Torr. & Gray, Fl. i. 182, 675. *A. arctica*, var. *β*, *grandiflora*, Hook. Fl. Bor.-Am. i. 100, t. 34, f. B. *Alsine macrocarpa*, Fenzl, Verbreit. Alsin. 18; Regel, Ost-Sib. i. 354, t. 8, f. 6–9; *A. arctica*, var. *breviscapa*, Regel. l. c. i. 347. Regel's elaborate subdivision of the Siberian forms of this species is not warranted in America in the absence of abundant fruiting material. — Western Alaska near the coast. (Siberia.)

+ + Species of the Atlantic and Gulf States, neither arctic nor alpine.

A. Caroliniana, Walt. Stems several to many, glandular-pubescent and viscid above. 3–8 inches in height, densely leafy near the base: leaves linear-subulate, rigidulous, pungent, triangular in section, channelled above; the lower imbricated and more or less squarrosely spreading; the upper reduced, distant: cymes few-flowered; pedicels slender, ascending: sepals oval, 1½ lines in length: petals broad, rounded at the apex. — Car. 141; Wats. & Coulter in Gray, Man. ed. 6, 85. *A. squarrosa*, Michx. Fl. i. 273; Ell. Sk. i. 520; Torr. Fl. N. Y. i. 95. *A. imbricata*, Raf. in Desv. Journ. Bot. (1808), i. 229. *A. Rafinesquiana*, Seringe in DC. Prodr. i. 409. *Alsine squarrosa*, Fenzl ex Gray, Man. ed. 2, 57; Gray, Gen. ii. 34, t. 111; Chapm. Fl. 49. — Pine barrens, S. New York to Florida.

12. **SAGINA**, L. Pearlwort. (Name from the Latin *saginare*, to fatten; the plants though small and delicate sometimes grow abundantly in otherwise barren regions and are grazed by cattle.) Low slender herbs commonly cespitose with filiform stems and subulate or filiform leaves; about a dozen species inhabiting the temperate and frigid parts of the northern hemisphere; one being also widely distributed in the southern hemisphere. — Gen. n. 336; DC. Prodr. i. 389; Gray, Gen. ii. t. 109.

* Very slender, 2–5 inches high: the almost capillary stems several to many, subsimple from near the base, usually several-flowered: the lowest flowers distinctly axillary: leaves nearly filiform but flattened above, not proliferous in the upper axils nor forming sterile lateral rosettes; the basal rosette seldom persisting: flowers very small, 4- or 5-parted.

S. apetala, L. Very slender and commonly glandular-pubescent: stems not numerous, procumbent or nearly erect: leaves very slender, 1½–3 or 4 lines in length, scarcely flat: pedicels straight; flowers normally 4-parted; petals obovate. — Mant. ed. 2, 559; Fenzl in Ledeb. Fl. Ross. i. 338; Torr. & Gray, Fl. i. 177. *S. procumbens*, var., Benth. Brit. Fl. 120. — Labrador, *Allen*, to Pennsylvania, infrequent but locally abundant in dry situations. A form with elongated capillary stems is abundant in grassy situations near Hewitt's, Bergen Co., N. J., *Britton*. Introduced at Auburn, California, *Mrs. Ames*. *Alsinella ciliata*, Greene, which is ambiguously characterized in the Flora Francis. 126, as a very slender and diffuse plant of compact habit, does not differ in its described characters from this species.

S. decumbens, Torr. & Gray. Annual, quite smooth or the younger parts slightly glandular: stems several, decumbent or suberect, 2–5 inches high, subsimple: the filiform straight peduncles exceeding the narrowly linear very acute leaves: flowers normally 5-parted: calyx appressed even in fruit, obtusish but not rounded at the base, $\frac{2}{3}$ the length of the capsule valves: petals scarcely equalling the sepals: stamens 10. — Fl. i. 177. *S. procumbens,* Pursh. Fl. 119. *S. Elliottii,* Fenzl ex Gray, Man. ed. 2, 61. *S. subulata,* Torr. & Gray, Fl. i. 178, not of Wimm. ? *Spergula nodosa*, Walt. Car. 142. *S. saginoides,* Michx. Fl. i. 276, not of Linn. *S. decumbens,* Ell. Sk. i. 523. *S. subulata,* Hook. Fl. Bor.-Am. i. 93. — New England to Great Plains of British America (*Macoun*), southward to Florida and Texas; on dry, sandy ground.

Var. **Smithii,** Wats. More slender: flowers apetalous, at least all the later ones. — Bibl. Index, 105; Wats. & Coulter in Gray, Man. ed. 6, 89. *S. subulata*, var. *Smithii*, Gray, Man. ed. 5, 95. Unsatisfactorily distinguished from *S. apetala* by its 5-parted flowers.

S. occidentalis, Wats. Annual, glabrous, with habit and foliage of the preceding species but with longer pedicels (usually 7–10 or 12 lines) and larger also 5-parted flowers: capsule $1\frac{3}{4}$ lines in length: calyx rounded at the base. — Proc. Am. Acad. x. 344. *S. procumbens*, Boland. Cat. 6; Torr. Bot. Wilkes Exp. 242 ? *S. Linnæi*, Gray, Proc. Am. Acad. viii. 378. *Alsinella occidentalis.* Greene, Fl. Francis. 125. — Vancouver's Island to Southern California, low grounds and salt marshes of the coast. The western equivalent of *S. decumbens*, possibly intergrading with that species.

S. procumbens, L. Matted: the numerous procumbent leafy stems $1\frac{1}{2}$–4 inches in length: leaves smooth or ciliate, narrowly linear, obtusish and mucronate: pedicels filiform elongated, nodding at the summit during anthesis: flowers normally 4-parted: petals considerably shorter than the sepals; the latter spreading in fruit. — Spec. 128; Torr. & Gray, Fl. i. 177. — Moist rocks, also in paths, etc., Nova Scotia to Pennsylvania, also rarely inland as far as Michigan. *Hill;* flowering through the summer. (Eu., Asia, S. Amer.) Apetalous forms have been noted in the Old World.

* * Stems very short, $\frac{1}{3}$–2 inches long; flowers rather small, 5-parted, terminal: leaves thickish, narrowly linear to subulate, not proliferous in the upper axils but almost always forming lateral sterile rosettes about the base.

S. Linnæi, Presl. Matted, 1–3 inches high: stems slender, decumbent, rooting and often producing lateral rosettes: radical leaves narrowly linear, acutely mucronate, 3–7 lines long, forming dense and mostly persistent rosettes; cauline leaves short, few: pedicels long, filiform, commonly recurved at the summit: flowers moderately large for the genus: petals not quite equalling the calyx: capsule ovate, conic, even before dehiscence considerably exceeding the sepals; the dry valves fully twice their length: stamens 5–10. — Rel. Haenk. ii. 14; Fenzl in Ledeb. Fl. Ross. i. 339; Wats. Bot. King Exp. 41. *S. saxatilis*, Wimm. in Lange, Pl. Grœnl. 133. *Spergula saginoides*, L. Spec. 441. *Alsinella saginoides*, Greene, Fl. Francis. 125. — Labrador, *Allen*, to Greenland, Alaska southward along the Rocky Mts. to New Mexico; also in Mariposa Co., Calif., *Congdon*.

S. nivalis, Lindbl. Very condensed, ½–1 inch high: leaves subulate, or linear subulate, 2–3 (rarely 5) lines long, forming one or more dense rosettes; cauline leaves few and short: pedicels spreading, 5 lines in length, straight or curved but scarcely ever hooked at the summit: petals equalling the purple edged sepals, about a line in length. — Bot. Not. 1845, 66; Hook. f. Arc. Pl. 287, 322; Babington, Seem. Journ. Bot. ii. 340; Wats. Bot. King Exp. 42. *S. intermedia*, Fenzl, l. c. i. 339. *Arenaria cæspitosa*, Vahl, Fl. Danica, xiii. t. 2289. — A rare plant. first collected in America by Dr. Watson in the Uinta Mts. in 1869 (Herb. Dep't of Agric.); since found in Alaska, without the exact locality, *Dall;* Kyska Harbor, *Harrington;* and also in the Rocky Mts. of Colorado near Gray's Peak, *Patterson*. The species has been regarded by some authors, and perhaps rightly, as a boreal or high alpine form of the preceding.

* * * Distinctly fleshy: stems not filiform, more or less branched, several-flowered: flowers 5-parted: species of the Pacific coast.

S. crassicaulis, Wats. Smooth: stems several or many, branching, 1½–5 inches long: leaves linear, pungent, thickish, 2½–7 (rarely 12) lines long; the basal forming a rosette which may persist or not; the cauline connate by broad scarious membranes: pedicels numerous, straight: petals and sepals subequal, 1½ lines in length: capsule ⅓–½ longer. — Proc. Am. Acad. xviii. 191. *Alsinella crassicaulis*, Greene, Fl. Francis. 125. — Beaches of Pacific coast, Marin Co., Calif., *Congdon;* Monterey Co., *Michener & Bioletti;* Ilwaco, Washington, *Henderson*. Distinguished from the Japanese *S. maxima*, Gray, by its glabrous peduncles and calyx.

* * * * Stems simple, 2–6 inches in length; upper leaves short, proliferous, i. e. bearing fascicles of minute leaves in their axils: flowers 5-parted: petals exceeding the calyx: species of the Atlantic Slope and Great Lakes.

S. nodosa, Fenzl. Perennial: stems several to many, decumbent, rooting at the base, often 5–6 inches in length: lower leaves filiform; the upper subulate, only a line in length, bearing a tuft of undeveloped leaves in the axils, thus giving a nodose appearance to the slender stems: flowers terminal, large for the genus, 4 lines in diameter when expanded. — Verbr. Alsin. t. 18, & Ledeb. Fl. Ross. i. 340. *Spergula nodosa,* L. Spec. 440. — Moist sandy soil. Coast of Maine south to Cape Ann, *J. Robinson;* also on both shores of Lake Superior and northward to Hudson Bay.

13. **SPERGULARIA**, Pers. (Name, a derivative of *Spergula.*) Annuals or perennials, usually of maritime and saline habitat, with narrowly linear, often fleshy leaves. A genus of moderate size but difficult, through the natural variability of certain species, the inconstancy of characters (such as the form of the seeds) which elsewhere are most trustworthy, and finally through an unfortunate complication in the synonymy, arising both from the most diverse views as to the number and proper limitation of the species and from the differences in the choice of the generic name. Space does not here permit any complete discussion of the last point. It may, however, be said that the name *Spergularia* is the only one which has ever attained a wide use, having been employed in such excellent popular manuals as Hooker & Bentham's Handb. Brit. Fl., Hooker's Fl. Brit. Isl., Garcke's Fl. Deutsch., Gray's Man., eds. 1–5, Cosson & Germain's Synop. Analyt., etc. Beside this matter of popular usage of the past, there is at present the best authority for selecting this name, since it is the one retained by the Kew botanists, and is advocated in the Berlin recommendations. On the other hand, the more radical reformers of nomenclature have attained no unanimity in regard to the proper name for the genus; Professors Baillon, Greene, and Britton adopting *Tissa,* Dr. Kuntze *Buda,* and Mr. N. E. Brown *Corion,* while Prof. Pax, who in his Monograph of the Caryophyllaceæ in Engler & Prantl's Nat. Pflanzenf. used *Tissa,* in a later publication has returned to *Spergularia.* — Syn. i. 504; Gray, Gen. ii. 27, t. 108; Benth. & Hook. Gen. i. 152. *Arenaria,* L. Gen. n. 374 in part. *Corion,* Mitchell, Act. Phys. Med. Acad. Nat. Cur. viii. App. 218, fide Britton in Britten's Journ. of Bot. xxix. 303; N. E. Brown, Suppl. Eng. Bot. *Tissa,* Adans. Fam. des Pl. ii. 507; Baillon, Hist. des Pl. ix. 116; Britton, Bull. Torr. Club, xvi. 125; Greene, Fl. Francis. 126, & Man. Bay Reg. 35. *Buda,* Adans. l. c. i. 507; Dumort. Fl. Belg. 110; Wats. & Coulter in Gray, Man. ed. 6, 89. *Lepigonum,* Fries, Fl. Hall. 76; Kindberg, Monogr.; Wats. Bibl. Ind. 103.

* Procumbent, or decumbent, slender, scarcely at all fleshy, growing near or even on the seacoast, but not truly saline: flowers small or of medium size: petals magenta: stipules lanceolate, elongated and conspicuous.

S. rubra, Presl. Usually annual, smoothish below, finely glandular-pubescent above: stems spreading, wiry: leaves flat above, narrowly linear, cuspidate, 4–6 lines long, $\frac{1}{3}$–$\frac{1}{2}$ line broad: stipules white, attenuate, 2–3 lines long: inflorescence racemiform; pedicels truly filiform, exceeding the bracts and about twice as long as the oblong-lanceolate scarious-margined acutish glandular-pubescent sepals: corolla $1\frac{1}{2}$ lines in diameter, scarcely equalling the calyx: capsule of the same length; seeds "semiobovate" and minutely crested but not winged. — Rel. Haenk. ii. 9; Gray, Gen. ii. 28, t. 108, & Man. ed. 1, 64 excl. var. *S. rubra*, var. *campestris*, Gray, Man. ed. 5, 95. *S. campestris*. Aschers. ex Rohrb. in Mart. Fl. Bras. xiv.^{2} 267. *Arenaria rubra*, L. Spec. 423 excl. var.; Bigel. Fl. Bost. 108; Hook. Fl. Bor.-Am. i. 98. *Buda rubra*, Dumort. Fl. Belg. 110. *Spergula rubra*, Torr. & Gray, Fl. i. 175 excl. vars. *Tissa rubra*, Britt. Bull. Torr. Club, xvi. 127. — An attractive species, growing about paths in dry sandy soil. Maine to Virginia, and Washington State, *Suksdorf;* to San Francisco, *Mrs. Brandegee.* (Europe.)

S. Clevelandi. Perennial, viscid-glandular: leaves ascending, often secund, conspicuously fascicled in the axils, almost terete and filiform, very acute and attenuate, 5–10 lines in length: flowers much as in the last, but often somewhat larger: seeds winged. — *Tissa villosa*, Britton, l. c. xvi. 129. *T. Clevelandi*, Greene, Fl. Francis. 127. *T. rubra*. K. Brandegee, Zoe, iv. 84. — Sandy soil, California, San Diego, *Cleveland*, *Mrs. Brandegee;* San José, *Mrs. Bush;* and at the Presidio, San Francisco, according to *Prof. Greene.* A doubtful species with close affinities, as Mrs. Brandegee suggests, to *S. rubra*, but not readily identifiable with any form of that species, as it seems to differ in its longer, more terete and acute leaves, and winged seeds. From the South American *S. villosa* it differs in its lower growth, distinctly smaller flowers, shorter pedicels, and somewhat firmer and less flaccid leaves.

* * Slender spreading or erect annuals of the West and Southwest, scarcely fleshy, and with short deltoid stipules.

+– Corolla pink (or white?) more than half as long as the sepals.

S. diandra, Boiss. Viscid-pubescent to nearly glabrous: leaves not fascicled, linear-filiform: pedicels slender, about 2 lines long, spreading or deflexed: sepals in fruit $1\frac{1}{2}$ lines long, but little exceeded by the capsules: stamens usually but 2–3. — Fl. Orient. i. 733. *Arenaria diandra*, Guss. Prodr. Sic. i. 515. *Tissa diandra*, Britton, Bull. Torr. Club, xvi. 128. — Texas, *Drummond*, *Lindheimer*, Goshen, Calif., *Mrs. Brandegee*, Oregon, *Henderson*, and on sandy banks of the Columbia River in Klickitat Co., Washington, *Suksdorf.* In its wiry procumbent stems this species also suggests *S. rubra*, from which, however, it differs in its short deltoid stipules.

S. gracilis. Low, glabrous, 2–6 inches in height, diffusely branched: leaves ⅓–1 inch in length: stipules deltoid: flowers small, subglobose, 1–1¼ lines in diameter, not closely aggregated; pedicels 2–3 lines long: sepals elliptic ovate, a line or less in length, thick in the middle but scarious-margined: valves of the capsule a third to a half longer than the sepals; seeds angled, somewhat triangular in outline, finely but distinctly roughened. — *Lepigonum gracile*, Wats. Proc. Am. Acad. xvii. 367. *Tissa gracilis*, Britton, Bull. Torr. Club, xvi. 128. — Sandy ground, dried ponds, etc. Dallas, Texas, *Reverchon*, to S. California, *Parry*, *Nevius*, *Orcutt.*

S. tenuis. Dichotomously much-branched, becoming 8–10 inches in height, somewhat glandular-puberulent or pubescent above: leaves 6–10 lines long: the very numerous flowers somewhat larger than in the last and inclined to be closely grouped; capsule twice the length of the ovate-oblong sepals. — *Lepigonum tenue*, Greene, Pittonia, i. 63. *Tissa tenuis*, Greene ex Britton, Bull. Torr. Club, xvi. 128. *T. diandra*?, K. Brandegee, Zoe, iv. 84. — California near Alameda, *Greene*, Mt. Eden and Tulare, *Mrs. Brandegee.* The affinities of this species are almost equally with *S. salina*, Presl, and *S. diandra*, Boiss., and in a large series of specimens it may not be possible to distinguish it sharply from either. The flowers, however, are more numerous and smaller and the corolla less developed than in the former; the habit also is much more branching. From *S. diandra* it differs in the usually much shorter pedicels of the closely aggregated and at first subcorymbosely arranged flowers.

* * * Annuals or biennials, more decidedly fleshy, usually of maritime or saline habitat: flowers small or of medium size: corolla more or less conspicuous, white or pink, less frequently pink-purple: stipules ovate or deltoid.

S. salina, Presl. Commonly although not always pubescent: leaves often fascicled in the axils: sepals ovate to oblong-lanceolate, narrowed upward although obtuse at the summit, 2–2½ lines long: petals pink: capsule equalling or a third to a half longer than the calyx: seeds turgid, obovate, usually roughened, less frequently nearly or quite smooth (var. *leiospermum*, N. E. Brown, Eng. Bot. Suppl.). — Fl. Cechica, 95; Gray, Man. ed. 5, 95; Warming, Bot. Foren. Festkr. 1890, 238, fig. 20. *S. Canadensis*, Don, Mill. Dict. i. 426. *S. rubra*, var. *marina*, Gray, Man. ed. 1, 64. *S. media*, and var. *macrocarpa*, Gray, Man. ed. 5, 95. *Arenaria rubra*, var. *marina*, L. Spec. 423. *A. marina*, Bigel. Fl. Bost. 109; Roth in Hornem. Fl. Dan. xiii. t. 2231. *Buda marina*, Dumort. Fl. Belg. 110. *Lepigo-*

num salinum, Fries, Mant. iii. 34. *L. marinum*, Kindberg, l. c. 18. *L. medium*, Wats. Bibl. Index, 103 in part. *Tissa marina*, Britton, l. c. xvi. 126. — Common on both the Atlantic and Pacific coasts, also occurring upon the Gulf coast, and not infrequent about salt lakes and in alkaline regions of the interior, especially westward.

Var.? minor. Smaller, 2–3 inches high: flowers smaller and very numerous, on short pedicels ($\frac{3}{4}$–2 lines in length) and consequently rather densely aggregated. — *Buda marina*, var.? *minor*, Wats. in Gray, Man. ed. 6, 90. — Coast of New Hampshire and Massachusetts. An ambiguous form suggesting the western *S. tenuis* but smaller and with a better developed corolla.

S. borealis. More slender and in well developed specimens more diffusely branched than the preceding, 2–5 inches high, glabrous: leaves opposite, seldom fascicled; stipules ovate, broader than long, obtuse or obtusish: sepals ovate, 1–$1\frac{1}{2}$ lines long, very obtuse: petals shorter, white or pink: capsule ovate-oblong, usually nearly or quite twice as long as the calyx; seeds usually wingless and nearly or quite smooth. — *Arenaria rubra*, *β*, Michx. Fl. i. 274. (Dr. Britton, who has examined the type of Michaux's variety, pronounces it identical with this species.) *A. Canadensis*, Pers. (Syn. i. 504), the oldest specific name, but not to be selected for use under *Spergularia*, since *S. Canadensis* has been used by Don (Mill. Dict. i. 426) for a "pilose" and "rather hispid" plant, extending from "Canada to Carolina" and being doubtless *S. salina*, Presl; *Lepigonum medium*, Wats. Bibl. Index, 103 in part. *Tissa salina*, Britt. l. c. xvi. 127. *Buda borealis*, Wats. & Coulter, in Gray, Man. ed. 6, 90. — Sea-beaches and tidal marshes, Maine to Labrador.

* * * * Stout and fleshy perennials of the Pacific slope: flowers large.

S. macrotheca. Smooth to densely glandular-tomentose: stems spreading, ascending, 8–15 inches in height; leaves linear, acute, mucronate, 8 lines to 2 inches in length, about a line in breadth; internodes more or less developed, usually $\frac{1}{2}$–1 inch long: floral bracts resembling the leaves: inflorescence inclined to be racemiform; pedicels 4–12 lines in length, spreading or more or less deflexed: sepals lanceolate, acutish or somewhat attenuate to an obtuse point, thick in the middle, nearly smooth or viscid-glandular, conspicuously membranous-margined: petals roseate, shorter than the sepals: capsule oblong-ovoid, acutish, nearly equalling the sepals. — *Arenaria macrotheca*, Hornem. ex Cham. & Schlecht. Linnæa, i. 53. *Lepigonum macrothecum*, Fisch & Mey. Ind. Sem. Petr. iii. 14; Kindberg, Monog. 16, t. 1, f. 1; Wats. Bibl. Index, 103. *L. Chilense*, Fisch &

Mey. l. c. *Spergularia rubra*, Torr. Pacif. R. Rep. iv. 70. — California, chiefly on or near the coast. A polymorphous species, the varieties of which, although diverse in aspect, appear in a large series of specimens to be thoroughly connected by intermediates.

Var. leucantha. Erect or nearly so, with long internodes: leaves somewhat narrower and more erect than in the type: floral bracts reduced and inflorescence more distinctly cymose; pedicels elongated, rather rigidly spreading or deflexed: corolla white, nearly 6 lines in diameter. — *Tissa leucantha*, Greene, Fl. Francis. 127. — A variety of alkaline regions of the interior. A form from Vanden (*Mrs. Brandegee*), identical in habit and foliage, has magenta flowers.

Var. scariosa. Low, pale, smoothish near the base, and often very glandular-viscid above, densely leafy; the internodes scarcely or not at all developed: leaves $\frac{1}{3}$–$\frac{1}{2}$ inch long, acute; stipules conspicuous, ovate-lanceolate, acuminate, 4–5 lines long: inflorescence racemiform; pedicels not greatly exceeding the calyx. — *Tissa macrotheca*, var. *scariosa*, Britton, Bull. Torr. Club, xvi. 129. *Tissa pallida*, Greene ex Britton, l. c. xvi. 129; Fl. Francis. i. 127. — Coast at Monterey, California, *Torrey; Hooker & Gray*, 1877; *Gray*, 1885; and at Fort Point, *Brandegee*. *Tissa valida*, Greene, Erythea, i. 107, appears to be a firmer and more erect form of the same thing, also pale and very viscid, but with more elongated internodes and distinctly dichotomous cymose inflorescence. — Island of Santa Cruz, according to Professor Greene.

SPERGULA, L. SPURRY. (Name from the Latin *spargere*, to strew, in reference to the scattering of the numerous seeds.) — Annuals with narrowly linear slightly fleshy apparently whorled leaves; one species common in America, having probably been introduced with grain from the Old World. — Gen. n. 375; Reichb. Iconogr. vi. t. 511–513.

S. ARVENSIS, L. A foot or two high: leaves numerous in rather remote whorls: inflorescence a terminal naked spreading cymose panicle; pedicels often deflexed in fruit: petals white, equalling or slightly exceeding the sepals, 2–2$\frac{1}{2}$ lines long: capsule ovate-globose; seeds black minutely roughened with light-colored papillæ, acutely edged but scarcely winged. — Spec. 440; Walt. Car. 142; Eng. Bot. xxii. t. 1535; Pursh, Fl. 320; Hook. Fl. Bor.-Am. i. 92; Torr. & Gray, Fl. i. 174; Rothr. Pl. Alask. 444. *S. ramosissima*, Dougl. ms. according to Torr. & Gray, l. c. — Grain fields and cultivated grounds, common, United States and Canada, northward to Alaska. (Introduced from the Old World.)

II. — DESCRIPTIONS OF NEW AND HITHERTO IMPERFECTLY KNOWN PLANTS COLLECTED IN MEXICO BY C. G. PRINGLE IN 1892 AND 1893.

Eriodendron tomentosa. Branchlets and petioles fuscous-tomentose; leaves 7-foliate; leaflets narrowly lanceolate, acuminate in both directions, sharply and finely serrate, sparingly hirsute upon the veins above, fuscous-tomentose beneath especially along the midrib, attenuate at the base to short scarcely distinct very tomentose petiolules: common petiole 2–3 inches long; stipules subulate, tomentose, persistent: peduncles short, thick: calyx turbinate-campanulate, 1½–1¾ inches long, finely tomentose on the outer surface, densely woolly within; teeth rounded, a fourth as long as the tube: petals red, linear-oblong, spreading, rounded at the apex, over 5 inches in length, 4–5 lines in breadth, silky-pubescent upon the outer surface, less pubescent or glabrate within: staminal tube 8 lines long, hirsute; free portion of the filaments spreading, exserted from the corolla; anthers anfractuose. — Collected on a barranca near Guadalajara, June, 1892 (no. 5300). This species is distinguished from *Eriodendron æsculifolia*, HBK., by its tomentose branchlets and foliage. The latter species is apparently represented by Mr. Pringle's no. 5324, from hills bordering on Lake Cuitzea, Michoacan, August, 1892, which accords in every regard with Kunth's description save that the leaflets range from 5 to 7 instead of 7 to 8. It differs, however, from Moçino and Sesse's Plate 94 in the Calques des Dessins, in having a glabrous calyx, and stamens really shorter than the petals; leaflets a little broader and distinctly petiolulate. As the plate shows the calyx to be pubescent and foliage as in *E. tomentosa*, it appears probable that it was not drawn from *E. æsculifolia*, as hitherto supposed, but really represents a distinct species, probably the *E. tomentosa* just described.

Ayenia glabra, Wats. The following additional characters may be given: fruit subglobose, shallowly 3-lobed, nearly 4 lines in diameter, light green, muriculately roughened with darker colored points; seeds dull brown, strongly rugose. — Collected in the barranca of Tequila, 2 and 17 October, 1893 (no. 4576).

Bursera Pringlei, Wats. (Proc. Am. Acad. xxv. 145). This species was described from fruiting specimens. Mr. Pringle's no. 4381, collected on lava beds near Zapotlan, 27 May, 1893, shows the following additional characters: staminate flowers yellowish green: sepals 5, ovate, acute, ½ line in length: petals 2 lines long, with involute margins: stamens 10; anthers linear-oblong, twice the length of the filaments: disk deeply crenate.

NISSOLIA CONFERTIFLORA, Wats., var. LAXIOR. Agreeing with the type in foliage and technical characters, but having flowers nearly twice as large (3½–4 lines in length) upon more elongated pedicels. — Collected in the barranca of Beltran, 5 June, 1893 (no 4379).

ÆSCHYNOMENE AMORPHOIDES, Rose in litt. *Brya* (?) *amorphoides*, Wats. (Proc. Am. Acad. xxii. 406). Excellent flowering and fruiting specimens of this plant, collected by Mr. Pringle in the barranca of Tequila, 1 October, 1893 (no. 4613), fully confirm the view expressed in a letter from Dr. J. N. Rose, that it should be referred to the genus *Æschynomene*. The stamineal tube early splits on the ventral or lower side, and the pods are in all respects those of an *Æschynomene*.

CLITORIA (?) SERICEA, Wats. (Proc. Am. Acad. xxii. 407). Additional specimens collected on rocky hills near Guadalajara, June and July, 1893 (no. 4449), show the flowers of this species not hitherto described. Calyx short, campanulate, silky-villous, with narrow acuminate spreading teeth equalling the tube: corolla light blue, villous upon the outer surface, 6–7 lines long; petals subequal in length; the standard erect, open, orbicular, slightly thickened at the insertion of the claw; alæ oblong, abruptly contracted to a short claw: style bearded upon the upper surface: stamens all united. — An anomalous plant with the calyx rather of *Centrosema* but the bearded style and other characters of *Clitoria*.

CALOGANIA PULCHELLA, HBK., var. RACEMOSA. Leaflets broadly ovate, acutish: all or nearly all of the flowers borne in leafless axillary racemes (4–6 inches in length). — Collected by Dr. Edward Palmer at Tequila, Jalisco, August to September, 1886 (no. 379), and by Mr. Pringle near Guadalajara, 15 September, 1893 (no. 5164).

GALACTIA MULTIFLORA. Stems slender, woody, grayish brown, much branched, ascending, not twining: twigs, petioles, and peduncles cinereous-tomentose: leaves pinnately trifoliate; leaflets oval or somewhat obovate, rounded or retuse at the apex, dull green and glabrate above, cinereous-tomentose beneath; veins slightly prominent beneath; the lateral veins 7 to 9 pairs, parallel; margin slightly thickened and revolute; terminal leaflet 15 lines in length, two thirds as broad; the lateral slightly smaller: racemes axillary, 2–3 inches in length: buds acutely lanceolate in outline: calyx purplish, silky-villous, deeply 4-cleft, 4 lines in length; the upper segment oblong, acuminate; the others linear or lance-linear, attenuate: corolla (in a dried state) deep purple, striated with green, 5–6 lines in length; standard obovate, entire at the base; alæ oblong, strongly auricled upon the upper edge; keel but slightly curved: stamens alternately shorter, one free. — Collected on rocky hills about Tequila, 1 July, 1893 (no. 4433). Fruiting specimens belonging to this species and collected in the same locality, 24 September, 1893, have leaflets 2–2½ inches in length, and oblong acuminate pubescent legumes.

ERIOSEMA MULTIFLORUM. A shrub, 3–4 feet high: stems brownish, furrowed-angulate, branched; branches covered with fine silky reflexed appressed pubescence: stipules ovate, acuminate, 2½–3 lines long, silky pubescent, tardily deciduous: leaves ascending, 3-foliate; common petioles 1–2 lines long; leaflets elliptic-oblong, obtuse, often apiculate, pale green, firm in texture, 3-nerved, finely pubescent above, appressed silky-villous beneath especially upon the prominent veins, 1½–2 inches long, a third as broad; the edges revolute: racemes crowded at the ends of the branches, subsessile, densely flowered, 1½–2½ inches long: bracts caducous ovate-rhombic, acuminate, silky, 2–3 lines long, somewhat exceeding the ascending pedicels: calyx finely pubescent, campanulate, rounded at the base, gibbous upon the upper side, parted to the middle; the segments lanceolate, attenuate; corolla yellow, 6 lines in length; standard with a slight bifornicate thickening just below the middle upon the inner surface; vexillar stamen free and with a bulbous thickening at the base: pods (scarcely mature) broadly oblong, shortly and obliquely acuminate, 7–8 lines in length, rufescent silky-villous, 2-seeded. — Collected on rocky hills near Tequila, 7 October, 1893 (no. 4548). This species stands near *E. grandiflorum*, Seem., but differs in its smaller, more numerous, and densely racemed flowers.

MIMOSA TEQUILANA, Wats. Excellent fruiting specimens found by Mr. Pringle on hillsides near Tequila, 26 September, 1893 (no. 4596), furnish the following characters not shown in the type: pods about 6 in a head, flat, thin, oblong, acute, about 3-seeded, ¾ inch long, 2½ lines wide, covered with weak transversely spreading prickles.

BEGONIA PALMARIS, A.DC. Mr. Pringle has been fortunate in rediscovering this species and securing the hitherto unobserved fertile plant. His excellent specimens, kindly identified by Monsieur Autran with the type in Herb. Boissier, furnish the following supplementary characters: plants apparently diœcious, 2–4 feet high: lower leaves much larger than the upper (hitherto described), becoming 8 or 9 inches broad: petioles 2 inches in length: lobes of the fertile flowers white, broadly ovate, acute, sharply denticulate, smooth or sparingly pubescent upon the outer surface; the three outer ones 9 lines long, 6 lines broad; the two inner somewhat smaller: pistil of § *Knesebeckia*, A.DC.; ovary pubescent; capsule 8 lines long, 3-winged; wings unequal, broadest near the base. — Fruiting specimens collected on a barranca near Guadalajara, 23 September, 1891 (no. 5178); flowering plants of both sexes were collected in rich soil on shaded rocky slopes of barranca near Guadalajara, 29 July, 1893 (no. 4474).

RANDIA WATSONI. (*R. tomentosa*, Wats. Proc. Amer. Acad. xxv. 152, not of Blume.) Mr. Pringle's no. 4383, collected on lava beds near Zapotlan, 20 May, 1893, corresponds to the type of Dr. Watson's species except in its somewhat more obtuse leaves, and doubtless should be referred to this species. It furnishes the following additional characters: buds clavate, an inch in length, curved upward: calyx silky, 3 lines in length; segments short, linear; sinuses rounded: corolla tube 9 lines long, hirsute upon the outer surface; limb abruptly spreading, nearly or quite an inch in breadth; segments oval: anthers oblong, apiculate, sessile in the orifice of the corolla: stigma 2-lobed.

VALERIANA PALMERI, Gray. Mr. Pringle's specimens of this plant show that the root terminates in a small oblong tuber-like enlargement about half an inch in length. — Collected on shaded banks near Guadalajara, 2 September, 1893 (no. 4521).

STEVIA SERRATA, Cav., var. OVALIS. Leaves short, oval, scarcely narrowed at the base, 10–12 lines long, 5–7 lines broad. — Collected by Dr. Edward Palmer on the Rio Blanca, Jalisco, July, 1886 (no. 309), and by Mr. Pringle on rocky hills near Guadalajara, 28 August, 1893 (no. 4491). Mr. Pringle's no. 602, from Chihuahua, 1886, is nearly the same.

GUARDIOLA ROTUNDIFOLIA. Glabrous: stem rigid, brown, finely furrowed: leaves thickish, ovate-orbicular, closely sessile and clasping, remotely denticulate, cuspidate, glaucous, 1½–2½ inches in diameter: inflorescences about 3-headed, closely subtended by floral leaves: scales of the involucre 4–5 lines long, finely striated, ovate, narrowed to an obtuse point: achenes 2½ lines in length, mottled, truncate, contracted below to a thick short stipe: corollas in a dried state greenish. — Collected on hills near Tequila, 15 October, 1893 (no. 4571). Near *G. platyphylla*, Gray, but with larger, more orbicular, less dentate, and more clasping leaves; fewer larger heads, with broader involucral bracts.

LIABUM CERVINUM. Arachnoid-tomentose, 2 feet in height: stem simple, leafy to the summit, furrowed, springing from large tuberous-thickened and clustered roots: leaves 5–6 inches in length, glabrate above, white woolly beneath except upon the nerves, narrowly connate, deeply and palmately cleft into linear attenuate one-nerved spinulose-denticulate segments; the latter 2–3 lines in breadth, with revolute margins: peduncles and involucres densely fuscous-tomentose: heads corymbose, about 6, discoid, an inch in height: scales of the involucre lance-linear; the outer shorter: corollas yellow, 5–6 lines long; the tube hirsute: achene silky; pappus tawny, readily deciduous. — Collected on bluffs of barrancas, San Marcos, 9 June, 1893 (no. 4398). Near *L. Palmeri*, Gray, but differing in its arachnoid and not glandular stem, leafy to the summit, its somewhat larger heads and more imbricated involucre, as well as in the more acute segments of the leaves, which in their mode of forking much resemble stag-horns.

ASCLEPIAS JALISCANA. Stem simple or sub-simple, erect, setose-hirsute, a foot in height: leaves sessile, oval to ovate-oblong, with rounded apex, sparingly hirsute upon both surfaces, ciliolate, glaucous beneath: flowers large, greenish, in several pedunculate, rather few-flowered umbels; peduncles 8 lines to 1 inch long, little exceeding the pedicels; both hirsute: calyx segments lance-linear, half as long as the corolla lobes; the latter reflexed, 5 lines in length, purplish upon the lower surface, green upon the upper: hoods 2½–3 lines long, scarcely at all auriculate at the inner angles; horn broad and conspicuously exserted: fruit tomentose, slender, fusiform. — Collected on the Rio Blanco, Jalisco, by Dr. Edward Palmer, in June, 1886 (no. 20); then by Mr. Pringle in plains near Guadalajara, June, 1889 (no. 3020), and again in dry soil, on plains and hills near the same city, July, 1893 (no. 4444). This species has the pubescence and much of the habit of *A. setosa*, Benth., with which it has been hitherto confounded. It is to be distinguished by its broader and more obtuse leaves, more glaucous beneath, its sub-simple stem, and its somewhat larger flowers with scarcely auriculate hoods and broad horns. Hartweg's no. 213, Bentham's type, as well as a number of other specimens correctly referred to his species, show that in it the horn is relatively slender and the hoods well auricled at the upper inner angles.

GONOLOBUS SORORIUS, Gray (Proc. Amer. Acad. xxii. 437), described from fruiting specimens, is now shown in flower by Mr. Pringle's no. 4435, collected on rocky bluffs above Tequila, 3 July, 1893. The following characters may be added: flowers in numerous axillary short-peduncled or subsessile umbels; pedicels 6–8 lines long: calyx segments lance-linear, obtusish, spreading or reflexed: corolla yellow, 5 lines in diameter; segments ovate-lanceolate, acutish; orifice covered with a conspicuous dense white beard: anther cells nearly upright: crown of five short obtuse scales, adnate to the base of the corolla. — In foliage and bearded corolla this species approaches *G. barbatus*, HBK., which, however, has larger flowers and is from the coast.

PHEROTRICHIS LEPTOGENIA. Densely hirsute: stems simple, erect, 1–2 feet in height, from a fusiform root: leaves short-petioled, obtuse; the lower oval, smaller, subcordate; the upper ovate to ovate-lanceolate: flowers in successive sessile intra- and super-axillary umbels; pedicels 3 lines long: calyx hirsute; segments lanceolate, acute, 1½ lines long: corolla 4–6 lines in breadth; its segments widely spreading, oblong-ovate, obtuse, greenish, striped with yellow, very thinly bearded or glabrate: corona equalling but not exceeding the stigma: membranous appendages of the anthers conspicuous: appendage of the stigma conical obtuse. — Collected on hills near Patzcuaro, 30 July, 1892 (no. 5279), and again on dry slopes near Guadalajara, 25 July, 1893 (no. 4466). Possessing the habit of *P. Schaffneri*, Gray, and *P. Balbisii*, Gray, but differing in its somewhat larger, more open and almost glabrous corolla. Mr. Pringle's no. 1148, collected in the Mapula Mountains of Chihuahua, 26 October, 1886, is the same, and shows the fruit to be lanceolate in outline, very acute and hirsute, 2½ inches in length.

EHRETIA CORDIFOLIA. A large tree with light brown glabrate branches; branchlets somewhat hirsute; lenticels conspicuous: leaves thick, of harsh texture, ovate, obtusish or very shortly acuminate, serrate, cordate or subcordate, scabrous above, paler and soft pubescent beneath, 2–3 inches in length, two thirds as broad; petioles pubescent, ½ inch in length: panicles terminal, only 1–1½ inches in length: sepals ovate-lanceolate, a line long: fruit oblong, 4-celled, 4 lines in length, 2½ lines in diameter. — Collected in valley, Zapotlan, 19 May, 1893 (no. 4382). Of this species fruiting specimens only are at hand. They possess a strong habital resemblance to *E. Mexicana*, Wats., but have broader cordate leaves.

IPOMŒA STANS, Cav., var. HIRSUTA. Very hirsute: leaves broad, sessile: sepals short, suborbicular. Collected by Dr. Edward Palmer on the Rio Blanco, Jalisco, August, 1886 (no. 324), and by Mr. Pringle on plains near Guadalajara, 30 August, 1893 (no. 4488). The typical form is merely puberulent, and has longer relatively narrower sepals.

IPOMŒA PERLONGA. Stem a little puberulent or glabrous, slightly armed with a few small scattered prickles: leaves orbicular, deeply cordate, shortly acuminate, entire, 2–4 inches in diameter, glabrous at maturity, somewhat paler beneath; petioles 1½–2½ inches in length: peduncles very long, becoming nearly a foot in length, each bearing a regular rather closely 6 to 12-flowered cyme: pedicels thickened upward and becoming deflexed in fruit, 3–8 lines long: sepals smooth, ovate-oblong, obtuse, apiculate, in anthesis but 2½ lines in length, becoming enlarged in fruit: corolla funnel-shaped, 1¾ inches long; the tube and throat rather slender, white; the limb bright blue (purple in dried specimen), 1⅓ inches in diameter: fruit globose, apiculate. — Collected on hills about Tequila, 15 October, 1893 (no. 4531). Distinguished by its strikingly long-peduncled inflorescences and markedly bicolorous corolla.

EVOLVULUS PROSTRATUS. Perennial: root perpendicular with horizontal branches: proper stem very short; branches 4 to 8, prostrate, simple, 4–6 inches in length, silky-villous: leaves imbricated in two rows and somewhat reflexed, suborbicular, rounded at the apex, rounded or subcordate at the base, 4–5 lines in diameter, subsessile, glabrous above, silky-villous beneath: buds and fruit entirely concealed beneath the leaves: flowers raised between them; peduncles 1½ lines in length, equalling the calyx, both villous: corolla white, 2 lines in diameter: capsule 2–3-seeded; seeds dull brown. — First collected by Dr. Thomas Coulter in Mexico without exact locality (no. 1011); then by Bourgeau in the Valley of Mexico at Santa Fé, 5 July, 1865–6 (no. 323), wrongly referred to *E. holosericeus*, HBK. Collected by Mr. Pringle on dry thin soil of hills near Guadalajara, 26 July, 1893 (no. 4445). In vegetative habit this species strongly suggests *Lysimachia nummularia*.

BASSOVIA DONNELL-SMITHII, Coulter (Bot. Gaz. xvi. 145). Mr. Pringle has rediscovered this Guatemalan plant in the barranca of Beltran, 6 June, 1893 (no. 4378). The range is thus considerably extended. His specimens and field notes show that the stem is about 10 feet high, twice regularly dichotomously branched. The calyx is somewhat accrescent, and the fruit is globular, orange-red, many-seeded, and about 5 lines in diameter.

PINGUICULA PARVIFOLIA. Base a small loose bulb, 4 lines in diameter, provided with a number of fine fibrous roots: leaves 3 to 5, elliptic-oblong, at the time of flowering not exceeding 3 lines in length and 1¼ lines in breadth; petioles margined and becoming broad and somewhat scarious below: scape single, strict or slightly curved, very minutely glandular near the summit: the five segments of the calyx subequal, lance-linear, acutish, scarcely exceeding 1½ lines in length: corolla 6–8 lines long; the limb bluish purple; the segments broadly oblong or somewhat spatulate; throat yellow as well as the tapering nearly straight or moderately curved spur (2–2½ lines in length). — Collected on mossy gravel bluffs near Guadalajara, 23 June, 1893 (no. 4397). An attractive little species distinguished by its paucity of foliage.

VITEX PYRAMIDATA. Tall shrub, 10–15 feet in height: branchlets, petioles, and inflorescences pulverulent-pubescent: petioles long, deeply sulcate above: leaflets 5, elliptic, mucronate, entire, rounded at the base, becoming decidedly coriaceous with age, green and smoothish above, with sulcate veins and minute reticulation, pale and tomentose beneath, 3–4 inches long, nearly half as broad; petiolules 3 lines long: the sulcate peduncles springing from the upper axils and bearing rather dense compound pyramidal panicles, sometimes subtended by two trifoliate bracts: calyx scarcely a line in length, shortly 5-toothed: corolla strongly bilabiate, about 6 lines long; the tube enlarged upward, about equalling the limb; segments rounded, ovate, the two upper suberect, the lowest the largest: stamens exserted, recurved at the summit, anther cells divergent: fruit 6 lines in diameter, consisting of a tough exocarp surrounding an irregularly sculptured woody endocarp, enclosing four 1-seeded cells. — Tequila, Jalisco, August, 1886, collected by Dr. Edward Palmer; rediscovered by Mr. Pringle on rocky hillsides about Tequila, 29 June, 1893 (no. 4429). Dr. Palmer's fruiting specimen was referred to *V. mollis*, HBK., by Dr. Watson (Proc. Amer. Acad. xxii. 444). He states also that the dark brown fruit is eaten by the natives under the name of "ahuilote." Mr. Pringle's flowering specimens show the plant to be amply distinct from *V. mollis*. The paniculate inflorescence is rare in American species although common in those of the Old World.

CYTINUS OXYLEPIS. Fuscous and somewhat granular-tomentose, 2–3 inches high: the short scaly stem not greatly enlarged at the base, and not equalling in length the thick clavate inflorescence: scales both of the stem and inflorescence lanceolate or ovate-lanceolate, acuminate, smooth, spreading, 1½ lines in length: flowers bisexual; segments of the perianth 6–7, ovate, acute, granular-fuscous upon the back, a line in length, united below into a shallow cup: anthers about 6, uniseriate and adnate to the short thick style: stigma obscurely lobed; ovaries more than half immersed in the thickened axis of the inflorescence; placentæ 5–6. — Collected on lava beds near Zapotlan, 13 and 27 May, 1893 (no. 4373). A fungoid parasite upon woody roots of Burseras. The stem is 3–4 lines in diameter and the inflorescence is 2–3 times as thick. The species appears to be distinguished from all other plants of the genus by its perfect flowers, as well as by its small and very acute scales.

PEDILANTHUS PRINGLEI. Stems smooth, alternately few-branched: leaves closely and softly puberulent upon both surfaces, lanceolate, acuminate, 1½–2 inches long, subsessile by an abruptly narrowed base; midrib prominent and white below; bracts minute, grayish tomentose, caducous; pedicels 1½–3 lines long: involucres acutish at the base, dark purplish red, 5 lines long; the upper lip quadri-glandular at the base inside, glabrous, abruptly bent, attenuate to a very narrow but truncate entire or slightly retuse apex; segments of the lower lip finely ciliated, otherwise glabrous; style slender, dark red, trifid; capsule smooth, 3–3½ lines in length upon a stipe (½ inch long); seeds ashy, ovoid, apiculate. — Collected on limestone ledges, Las Palmas, San Luis Potosi, 25 July, 1891 (no. 5107). Near *P. Tithymaloides*, Poir., but with smaller puberulent leaves, darker colored involucre, acutish at the base and with a more slender and attenuate upper lobe.

ACALYPHA HYPOGÆA, Wats. (Proc. Am. Acad. xxii. 451). Has been rediscovered by Mr. Pringle on damp slopes near Guadalajara, 28 July, 1893 (no. 4460). His specimens show the following additional characters: stem hirsute, 4–6 inches in height: the largest leaves 15 lines in length: staminate spikes very small, 1–2½ lines long, upon slender axillary often deflexed peduncles (a line in length).

ACALYPHA POLYSTACHYA, Jacq. *A. filifera*, Wats. (Proc. Am. Acad. xxii. 451), has been again found by Mr. Pringle in Jalisco (no. 4470). As Dr. Rose notes, this species is not to be distinguished from *A. polystachya*, Jacq., represented by a rather wooden plate in the Hortus Schönbrunensis.

LIPARIS GALEOTTIANA, Hemsl. This species, insufficiently characterized by Richard and Galeotti, Ann. Sci. Nat., ser. 3, iii. 18, as *Malaxis Galeottiana*, was transferred to Liparis by Mr. Hemsley, Gard. Chron. 1879, i. 559. No exact occurrence of the plant in Mexico was known until Dr. Watson, Proc. Am. Acad. xxii. 454, doubtfully identified with the description a specimen collected by Dr. Palmer on the Rio Blanco, Jalisco. Mr. Pringle has secured the same plant on the Sierre Madre, Chihuahua, 30 September, 1887 (no. 1527), and on moist slopes, Patzcuaro, 18 July, 1892 (no. 5274), and finally on dry granitic hills near Guadalajara, 17 August, 1893 (no. 4512). A portion of the last mentioned specimen was sent to Kew, where it was definitely identified with the species in question. Mr. Pringle's specimens bear out Dr. Watson's amplification of the characters, and confirm its distinctness from *L. elliptica*, Reichb. f.

ISOCHILUS UNILATERALE. Glabrous: stems several, slender, simple, 8 inches in height, roughened especially near the base by numerous minute warts: leaves linear, slightly retuse, rather rigidly erect, 1½–2 inches long, finely striated: racemes single, simple, terminal, secund, about 7-flowered: bracts oblong, obtuse, purplish; pedicels exserted 2–3 lines: flowers large for the genus, 6 lines long, purple, strongly gibbous upon the side toward the labellum, not noticeably fleshy: sepals subequal in length, carinate, acutish: petals oblong, obtusish, slightly broader than the sepals, and not carinate; labellum lance-oblong, with the sigmoid flexure characteristic of the genus but without lateral lobes: fruit 6 lines in length. — Collected on oaks, Tamasopo Cañon, 23 June, 1891 (no. 5116). This species, with much the habit of *I. lineare*, R. Br., has larger more one-sided flowers in a looser raceme.

NEMASTYLIS FLAVA. Bulb ovoid, 8 lines in diameter, dark brown, with a tuft of fibrous roots at the base; stems or rather scapes 1 to 3, slender, simple, leafy only at the base, 8–10 inches high, bearing at the summit a single 2–3-flowered spathe of 3 unequal lance-linear or linear-oblong acuminate bracts (the largest 1½–1¾ inches in length): the outer leaves reduced to acute scale-like sheaths; the inner narrowly linear, attenuate, equalling the scape: pedicels about an inch long: flowers 1–1¼ inches in diameter, bright yellow: segments oblanceolate to obovate, acuminate; the outer 7 lines in length; the inner two thirds as long and with rounded thickened areolæ at the base: filaments connate; column 1½ lines high; anthers 2½ lines long, inclining to curl with age: capsule ovoid, smooth, shallowly six-furrowed, ½ inch in length. — Collected on gravelly soil near Guadalajara, 23 June and 21 August, 1893 (no. 4400). Near *N. bracteolata*, Baker, but with single heads, distinctly unequal perianth segments, and, of course, different geographic position.

DIOSCOREA GRANDIFOLIA, Schlecht. Mr. Pringle's no. 4547, collected on talus of cliffs, barranca of Tequila, 4 October, 1893, corresponds well to the characterization of this species. The fertile plant, of which I find no description, furnishes the following characters: fruiting racemes about 3 inches in length upon peduncles about an inch long: fruit elliptic in outline, reflexed-spreading, not closely imbricated, 7 lines in length, half as wide.

D. PRINGLEI. Glabrous: stem twining: leaves ovate, acuminate, entire, cordate with an open sinus, 9–11-nerved, somewhat paler beneath, 2–3 inches in length, about the same breadth: flowers of the staminate plant in slender compound racemes; the latter scarcely pedunculate, either solitary in the axils or borne at the successive nodes of the leafless ends of the stem; branches of the racemes numerous, about 5-flowered, the uppermost reduced and fewer-flowered: pedicels ½ line long: bracts lance-linear, acuminate: perianth campanulate, pale yellow; segments obovate, rounded at the ends, 1¼ lines in length: stamens 3; filaments slender; rudiments none: fertile racemes axillary, short-peduncled, in fruit 2–3 inches in length: fruit suborbicular, retuse, 3½ lines in diameter (immature). — Collected on grassy slopes of barranca near Guadalajara, 7 September, 1893 (no. 4526).

D. HIRSUTICAULIS. Pubescent-hirsute throughout with crisped white hairs: stem elongated, twining: leaves deltoid-ovate, acuminate, entire, cordate with an open sinus, about 9-nerved, 2–3 inches long, nearly as broad; petioles 8 lines in length: racemes of the staminate plant slender, simple, about 1½ inches in length upon peduncles perhaps half as long, solitary in the axils or borne at the *successive nodes of the nearly leafless ends of the stems; pedicels* but ⅓–½ line in length: perianth campanulate, a line in diameter; segments ovate-oblong, obtuse: stamens only 3, filaments short and straight: inflorescences of the female plant axillary, solitary, in fruit 1¼ inches in length, ¾ inch in diameter: fruit stramineous, broadly elliptic, smooth, 4½ lines in length, 3½ lines in breadth, reflexed and very densely imbricated. — Collected under dry ledges, barranca of Tequila, 14 October, 1893 (no. 4572).

D. PLUMIFERA. Glabrous: stems twining: leaves thin, ovate acuminate, entire, cordate with a broad sinus, 7–11-veined, slightly paler beneath, 2½–3 inches long, 2 inches broad: staminate flowers yellowish green, 2½ lines in diameter, borne in long slender feathery panicles; the latter geminate at the axils, 4 inches in length, ½ inch in diameter; the numerous short lateral branches about 3-flowered; pedicels ¾–1 line long, very slender: bracts lance-linear, acuminate, 1 line in length: segments of the perianth oblong-lanceolate, obtuse: fertile stamens 3, slender, not at all rigid or divaricate, alternating with 3 rudiments: racemes of the fruiting plant short-peduncled, densely flowered, 2 inches in length: fruit (scarcely mature) broadly elliptic, 4 lines long, reflexed, imbricated. — Collected under cliffs, barranca of Tequila, 14 October, 1893 (no. 4530).

D. MILITARIS. A slender vine 2–4 feet in length: stem smooth, from a small tuber: leaves rather distant, 3-lobed and halberd-shaped, hirsute-pubescent upon both surfaces; the central lobe lanceolate attenuate to a sharp point, 3-nerved, 1¼–2½ inches long, 3–7 lines broad; lateral lobes 6–8 lines long, somewhat falcate, obtuse; the uppermost leaves reduced, entire; petioles ½ inch long: staminate racemes slender, loosely flowered, including the peduncle 2–4 inches long: pedicels ½ line long, equalling or somewhat exceeding the minute subulate bractlets: perianth 1¼ lines broad; segments of two forms; the 3 outer spreading, oblong, obtuse; the inner a little narrower and acutish, ascending, incurved: stamens 3, very short, perhaps one third as long as the segments of the perianth: fruiting raceme 1½–2 inches long upon peduncles of nearly equal length: capsules glabrous, reflexed, somewhat imbricated, elliptic in outline, 6 lines long, half as broad. — Collected upon the steep sides of wet cliffs of the barranca of Guadalajara, 8 September, 1893 (no. 5434).

III. — NOTES UPON THE GENUS GALINSOGA.

FEW genera have been subject to so much doubt as to proper limitation as *Galinsoga*. This is equally evident from its treatment in De Candolle's Prodromus, in which of its supposed six species five are questioned, and from the writings of subsequent authors who have dealt with it. Satisfactory generic limitations can perhaps only be obtained by a monograph including not only the plants hitherto ascribed to *Galinsoga*, but several neighboring genera, for which sufficient material could only be found in the larger foreign collections. Something, however, may well be done at more accurate specific and varietal definition of forms growing within our own country. So far as I know, only one species is at present recognized upon the continent of North America north of Mexico, that is *G. parviflora*, Cav. The telling characteristics of this species, when obtained from the earliest descriptions and figures as well as from the examination of material completely in accord with these, are as follows: stem and branches smoothish or finely and more or less appressed pubescent: rays white or whitish, little exserted: pappus of the disk flowers consisting of spatulate obtusish scales equalling the achene. Of this species several varieties have been suggested. Dr. Gray in the *Pl. Wrightianæ*, ii. 98, founded two upon the relative development or absence of the pappus in the ray flowers; namely, var. SEMICALVA, with naked ray achenes, and var. CARACASANA, with abortive ray pappus. The writer has examined a large number of specimens of the species both from North America and from the most widely separated regions of the world, and finds that the ray pappus is never developed as in the disk flowers, but is always more or less abortive, consisting of fewer, shorter, and more slender bristles. Furthermore, the variation in its development seems absolutely independent of any other characters either floral or habital, so that varieties founded upon this character can have no more than formal value. Indeed this is the view which Dr. Gray subsequently took in the *Synoptical Flora*, i. 303. On the other hand, the form and length of the pappus in the disk flowers seem more worthy of note, and several plants have recently been received at the Gray Herbarium which differ so materially in this regard and in their greater hispidity from the typical *G. parviflora*, Cav., as to call attention to the group. In those plants from the Eastern and Middle States, as cited below, the pubescence of the upper internodes is not only considerably more copious but much more spreading, the rays are bright white and well exserted, and the pappus scales of the disk flowers, while in length about equalling the achenes as in *G. parviflora*, have a very different form, being narrower and attenuate to a bristle-like apex. One of these specimens, collected by Mr. H. L. Clark at Pittsburg, Pa., was forwarded to Geneva for comparison with De Candolle's *G. parviflora*, var. *hispida*, and has been pronounced by M. Buser identical with that variety. Still a third plant of this genus quite distinct from the preceding has been collected upon waste land about Camden, N. J., by Mr. C. F. Parker. It is characterized by considerable pubescence, distinctly purple rays, and disk pappus but half as long as the achene. Portions of this plant have been forwarded to Geneva and Kew for comparison with *Vargasia Caracasana*, DC., and *Galinsoga hispida*, Benth., and it proves identical with both, while garden specimens of Regel's *G. brachystephana* show it with scarcely a doubt to be the same. This shows that Dr. Gray was in error in regarding his *G. parviflora*, var. *Caracasana* the equivalent of De Candolle's *Vargasia Caracasana*. While Mr. Parker's plant from Camden, the weed-centre of the United States, by no means shows this species of tropical origin to be established in our country, it may well be found that a portion of what has been hitherto referred to *G. parviflora* is this plant, especially as it is more or less extensively introduced in Eastern Europe, where it bears the name *G. brachystephana*, Regel. Summing up the different forms as well as the material at hand permits, we may divide them as follows.

* Rays white, pappus of the disk flowers about equalling the achene.

G. PARVIFLORA, Cav. Smoothish, the upper internodes with a sparing sub-appressed pubescence: pappus of the disk flowers of spatulate obtusish scales. — Ic. iii. 41, t. 281; DC. Prodr. v. 677; Gray, Syn. Fl. i. 303, including vars. *semicalva* and *Caracasana* of Pl. Wright. *Bidens mercurialis folia*, &c., Feuillée, Journ. Obs. Phys., &c. ii. 744, t. 32. — Generally distributed from New England to Oregon and southward to Mexico.

Var. HISPIDA, DC. Prodr. v. 677. Pubescence especially of the upper internodes more copious and not at all appressed: scales of the pappus in the disk flowers attenuate and bristle-tipped: foliage, etc. as in the type. Alleghany City, Pa., 9 August, 1869, *Porter;* Milwaukee, Wisc., October, 1881, *Sherman;* Providence, R. I., 5 July, 1892, *Bailey & Collins;* Pittsburg, Pa., 1893, *Clark;* Cambridge, Mass., and doubtless widely introduced. The same thing has been recently collected in Central America by Capt. John Donnell Smith, nos. 759, 2352, where it is doubtless indigenous. While in general readily distinguishable by the characters described, this variety occasionally so intergrades with the type that specific distinction seems very undesirable.

* * Rays purplish: pappus of the disk flowers but half as long as the achenes.

G. HISPIDA, Benth. Bot. Sulph. 119. The oldest name under the genus. *G. brachystephana*, Regel in Walper's Rep. vi. 722. *Vargasia Caracasana*, DC. Prodr. v. 676. Doubtfully established at Camden, N. J., 15 September, 1870, *C. F. Parker.* So far as the northern and eastern parts of our country are concerned, all these plants are doubtless introduced; in Texas, New Mexico, and Arizona forms of *G. parviflora* may well be indigenous, as Dr. Gray suggests.

IV. — MISCELLANEOUS NOTES AND NEW SPECIES.

SILENE SUBCILIATA. Perennial: stem strict, terete, glabrous, a foot and a half high, enlarged at the nodes: leaves glaucous, slightly fleshy and finely lepidote, narrowly oblong to linear-oblanceolate, glabrous on the surfaces but sparingly ciliated, 1½–2 inches long, obtusely pointed with callous tips, narrowed below to winged commonly ciliated petioles; floral leaves reduced to lance-linear acute bracts: flowers rather distant, pedicellate, forming an elongated racemiform inflorescence: bractlets lance-linear, ciliated: calyx glabrous, cylindric, 10 lines in length: petals deep red, 1¼ inches long; the blade elliptic, entire, obtuse; the appendages lanceolate, entire: fruit and seeds not seen. — Type in the Gray Herbarium, collected by Mr. Charles Wright, but without number or date, and bearing only the locality "Texas and Louisiana." It is to be hoped that this attractive species may be rediscovered. It is evidently related to *S. regia,* Sims, and *S. laciniata,* Cav., but differs from the former very much in the form of its leaves, from the latter in its entire petals, and from both in the entire absence of glandular pubescence. From *S. Virginica,* L., it differs in petals, pubescence, and texture of the leaves.

SILENE LACINIATA, Cav. Prof. W. R. Dudley calls my attention to the fact that the seeds in this species and its broad-leaved variety (*S. Greggii*) are not infrequently vesicularly crested, as in the Californian *S. Parishii*, Wats.

ARENARIA GRŒNLANDICA, Spreng. This attractive species, possessing a wide and interesting north and south distribution, seems worthy of special study. The typical form, with subglobose obtusely pointed capsules and with stems few and decumbent from a spreading rosette of somewhat fleshy leaves, occurs chiefly in Greenland and Labrador. The common form of the mountains of Maine, New Hampshire, and Eastern New York becomes rather densely matted, and has many erect stems with very numerous erect less fleshy leaves about the base. Its capsules are ovoid to oblong and more or less acutely pointed. Although in temperate latitudes usually confined to rocky soil of the mountains or higher hills, this species descends nearly or quite to the seashore in Maine, at Bath and at Mt. Desert. It has also been found at Middletown, Conn. When growing at these lower altitudes, the plant is scarcely at all matted and the segregated few-stemmed individuals have simple or at least less fibrous roots and fewer thicker leaves than in the mountain form, with which however they are connected by frequent intergradations. In these forms also the capsule is ovoid or oblong rather than globose. Until recently the Shawangunk Mountains of New York have passed as the southern limit of this species, but there can be no doubt (see Mem. Torr. Club, iii. 14) that many of the specimens from the higher Mountains of North Carolina, hitherto referred to *A. glabra,* Michx., are practically identical with the plant of the White Mountains, notwithstanding the fact that the flowers average smaller. The question whether it is best to retain these forms of temperate regions in the same species with those of Greenland and Labrador presents much difficulty. The differences in habit, size of the flowers, and notching of the petals are often striking. Unfortunately, however, no one of these characters holds satisfactorily in a large series of specimens, and it appears that the change from the few-stemmed decumbent plant with a basal rosette of leaves and single simple root to the matted plant with fibrous roots and many stems, erect by mutual crowding, is a difference which may well be due exclusively to the greater length of the season. As to the size of the flowers, a series of specimens collected at Mt. Desert by Mr. Redfield and Mr. Rand conclusively shows that this is largely a function of the season, the autumnal flowers being much smaller than the earlier ones, indeed far smaller than those of the southern form. The shape of the capsule gave promise of furnishing a good character, but the difference between globose and ovoid is not a sharp one, and on examination it proves that subglobose capsules occasionally occur in the White Mountain plant, and even in the few Greenland plants which could be examined the capsules were found to vary to ovoid, so that no sharp distinction can be founded upon this character.

DALEA NEGLECTA. Branches slender, terete, glabrous, glandular-punctate: leaves smooth, 1½–2 inches in length; leaflets 5–7 pairs and odd one, 4–5 lines long, elliptic or oblanceolate, petiolate, obsoletely crenate, rounded at the apex, acute at the base, smooth and veinless above, glaucous, glandular-punctate and 1-nerved beneath: peduncles very slender, equalling or exceeding the curved loosely-flowered spike (1½ inches in length): flowers 2½–3 lines long, spreading or reflexed upon very short pedicels: calyx turbinate, strongly ribbed with yellow glands and covered with very short upwardly appressed or rather incurved hairs; teeth lance-linear, acute, inflexed, nearly equalling the tube: corolla in dried specimens bright purple. — Collected at Guanajuato, Mexico, by Prof. Alfred Dugès (no. 2576). Habit nearly of *D. nutans*, Willd. The peculiar pubescence of the calyx appears rather exceptional in the genus, being in most species straight, silky or lanate.

SAXIFRAGA PENNYSLVANICA, L. A specimen of this species, collected at Royalton, Vt., with deep red petals, has recently been received at the Gray Herbarium from Miss Emily P. Robinson of Manchester, N. H. A hasty search in the literature of the species has failed to show any record of this variation, the petals being always described as greenish or yellowish green. As the anthers are bright orange, the dark red or crimson petals give to the flowers a much more striking contrast of color, doubtless correlated with insect pollination. So far as observed, the specimen in question presented no other differences from the typical form.

ASTER PAUCICAPITATUS. Stems several, simple, flexuous, leafy to the summit, ribbed, somewhat pubescent, 10 inches to 1½ feet high: leaves elliptic-oblong, obtuse or obtusish, mucronulate, sessile by a scarcely narrowed base, finely and somewhat glandularly pubescent, 9–16 lines long, 3–5 lines broad, erect or ascending: heads usually single, terminal, short-peduncled, less frequently 3–4, corymbose, including the rays 1¼–1½ inches in diameter: involucre of few subequal lance-linear attenuate finely pubescent and ciliolated scales; the latter loosely imbricated in 2–3 series, rather firm and broadly white-margined near the base, 4 lines long; the very acute tips often purplish: rays 12–18, white or pink, 6 lines in length, 1½ lines in breadth, 3-toothed at the apex; disk flowers including the silky achenes 5 lines in length: pappus rather copious, of unequal bristles but not distinctly double. — *A. Engelmanni*, Gray, var. (?) *paucicapitatus*, Robinson, Proc. Am. Acad. xxvi. 176. — Collected by C. V. Piper in the Olympic Mountains, Washington, August and September, 1890 (nos. 926, 934). Never satisfied with the earlier and somewhat provisional disposition of this plant, I have returned to its study, and conclude that it is specifically distinct from *A. Engelmanni*, through its much less imbricated involucre of subequal scales. It should stand in the genus near *A. Xylorhiza*, Torr. & Gray.

DIOSCOREA DUGESII. Stem slender, climbing, angulate, sparingly pubescent with fine brown hairs: leaves ovate, cordate, sharply acuminate, thin, 9-nerved, pellucid-lineolate, nearly or quite smooth, 2½ inches long, 2 inches broad; petioles pubescent, 1½ inches long: staminate flowers 1½ lines in diameter, borne in short slender simple solitary axillary pubescent racemes 1½–2 inches in length: peduncles but 2 lines long; pedicels scattered, ½ line in length, 1–3-flowered: bracts subulate, considerably exceeding the pedicels: segments of the perianth linear-oblong or linear-lanceolate, obtuse, with crisped margins: stamens six, equal, inserted on the perianth near its base, half as long as the segments. (Fertile plant not seen.) — Collected by Prof. Alfred Dugès at Guanajuato, 1880 (no. 37). A slender species, somewhat resembling *D. remotiflora*, Kunth.

XV.

ON THE INHERITANCE OF ACQUIRED CHARACTERS IN ANIMALS WITH A COMPLETE METAMORPHOSIS.

BY ALPHEUS S. PACKARD, M. D

Presented January 10, 1894.

I. THE PHYSICAL BASIS OF HEREDITY.

BEFORE discussing our subject it may be well to give a brief historical sketch of the present views as to the physical basis of heredity.

As early as 1849, Owen, in his "Comparative Anatomy," suggested that there was a physical basis for heredity. Herbert Spencer, in his "Principles of Biology" (1866), based the phenomena of heredity on the supposed presence of "physiological units," which he conceived to be immensely more complex than chemical units or molecules. (Vol. I. p. 183.) But Darwin in 1868 brought the question to the front in his "Hypothesis of Pangenesis," which was disproved by experiments on the effects of transfusion of blood by Francis Galton,* who in 1875 published a theory of heredity which in some ways approached that of Jaeger.

Galton also claimed that acquired characters are only "faintly heritable," and he endeavors to explain the almost complete non-transmission of acquired modifications. †

The first, however, to suggest an objective and scientific basis appears to have been Dr. G. Jaeger, of Germany, who in 1876 made the following statement, as quoted by J. A. Thompson in his "History and Theory of Heredity." *

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* Galton in 1875 suggested that each individual may properly be conceived as consisting of two parts, one of which is latent, and only known to us by its effects on posterity, while the other is patent, and constitutes the person manifest to our sense. "He also claimed that we are made up bit by bit of inherited structures, like a new building composed of the fragments of an old one, — one element from this progenitor, another from that, although such elements are usually transmitted in groups." — A Theory of Heredity, Journal of the Anthropological Institute, 1875. See also Contemporary Review, December, 1875.

† Contemporary Review, 1875, Vol. XXIII. p. 95.

"Through a great series of generations the germinal protoplasm retains its specific properties, dividing in every reproduction into an ontogenetic portion, out of which the individual is built up, and a phylogenetic portion, which is reserved to form the reproductive material of the mature offspring. This reservation of the phylogenetic material I described as the continuity of the germ protoplasm. Encapsuled in the ontogenetic material the phylogenetic protoplasm is sheltered from external influence, and retains its specific and embryonic characters." †

In 1880 M. Nussbaum ‡ substituted a new hypothesis for Darwin's pangenesis. According to the view of this observer, the germinal cells from which the sexual products are derived are separated off from the other cells of the embryo very early, and undergo little alteration. Hence he concluded that some of the original germ substance is directly abstracted from the egg, and preserved without essential alteration to become, by giving rise to the sexual elements, the germ substance of another generation. Nussbaum also expressed his disbelief in the transmission of acquired characters. This belief, held by Darwin as well as by Lamarck, and almost universally adopted by medical men, had not before been called in question.

In 1884 Nägeli § took the ground that there are in every living cell two substances; one the nutritive plasm, and the other his hypothetical "idioplasma." This view was indorsed by Kölliker, who claimed that the sharp distinction between body and germ cells does not exist.

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* Proc. Royal Society Edinburgh, 1889, pp. 91–116. See also Brooks, "The Law of Heredity," 1883; Osborn, "The Cartwright Lectures," 1892; "Present Problems in Evolution and Heredity," Medical Record, New York, 1892; "The Present Problem of Heredity," Atlantic Monthly, March, 1891.

† Lehrbuch der algemeinen Zoologie, Leipzig, 1878, II. Abtheilung. In a previous book, published at an earlier date than the one quoted by Thompson, Zoologische Briefe, Wien, 1876, Jaeger writes thus: "Hier muss ich noch einmal den Gegensatz zwischen Darwin's Theory von der Pangenesis und meiner Theorie von der Continuität des Keimprotoplasmas hervorheben" (p. 326).

See also Weismann, "The Germ Plasm," p. 200. The author appears to have overlooked the statement of Jaeger in his Zoologische Briefe, wherein he explicitly, as shown by our quotation, refers to the "continuity of the germ protoplasm."

‡ Die Differenzirung des Geschlechts in Thierreich. Archiv für mikroskop. Anatomie, Bd. XVIII., 1880.

§ Nägeli, Mechanisch-physiologische Theorie der Abstammungslehre. München u. Leipzig, 1884.

In 1887 Minot* in a brief note suggested that Nägeli's hypothetical idioplasm is probably identical with the nuclear chromatin of morphologists; and that heredity is due to the transfer from parent to offspring of the nuclear substance.

Maupas,† in two memoirs published in 1889 and 1890, reaffirmed and extended this view, concluding that the chromatin of all cells is the bearer of heredity.

Meanwhile in 1885 appeared Weismann's epoch-making essays on heredity, his view being somewhat in the line of Jaeger's theory, but greatly expanded, and with many new and original suggestions. He stated that it was impossible to prove the existence of gemmules, and substitutes for pangenesis the now famous doctrine of "the continuity of the germ plasm," as affording a more rational basis than pangenesis or Brooks's modification of it. Weismann says: "The nature of heredity is based upon the transmission of nuclear substance with a specific nucleoplasm of the germ cell, to which I have given the name of germ plasm" (p. 180). As stated by Mr. E. B. Poulton,‡ an able commentator and exponent of Weismann's views, —

"The word 'continuity' expresses the theory that heredity depends on the fact that a minute quantity of this germ plasm is reserved unchanged during the development of the individual, and afterwards grows and gives rise to the germ cells. Hence the germ plasm is continuous from one generation to another in an unending succession, and from it the germ cells of each generation are produced.

"Parent and offspring resemble each other because both arise from the same substance, which develops rather later in the case of the offspring. Hence everything which is predetermined in the germ cell, every blastogenic character, may be transmitted, while somatogenic characters cannot be transmitted."

We will quote Weismann's definition of acquired and blastogenic characters: "We maintain that the '*somatogenic*' characters cannot be transmitted, or, rather, that those who assert that they can be transmitted must furnish the requisite proofs. The *somatogenic* characters not only include the effects of mutilation, but the changes which follow from increased or diminished performance of function, and those which are directly due to nutrition and any of the other external influences which act upon the body. Among the *blastogenic* characters, we include not only all the changes produced by natural selection operating upon variations in the germ, but all other characters which result from this latter cause." (p. 413.)

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* Science, New York, VIII. 125.

† Sur la Multiplication des Infusoires Ciliés. Archiv de Zoologie expérimentale, sér. 2, VI. 165–273; Le Rajeunissement Karyogamique chez les Ciliés, VII. 149–517. See also Hartog, Quart. Journal Microscop. Science, December, 1891, and Osborn, *loc. cit.*, pp. 54–56.

‡ Theories of Heredity. Reprinted from the Midland Naturalist, November, 1889.

Weismann remarks that Nägeli has shown that even in so minute a space as $\frac{1}{1000}$ of a cubic millimeter such an enormous number (400,000,000) of "micellæ"* may be present that the most diverse and complicated arrangements become possible. It therefore follows that the molecular structure of the germ plasm in the germ cells of an individual must be distinguished from that of another individual by certain differences, although these may be but small; and it also follows that the germ plasm of any species must differ from that of all other species. (Weismann, p. 191.) It also follows, the author contends, that the molecular structure of the germ plasm in all higher animals must be very complex, and at the same time this complexity must gradually diminish during ontogeny.

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* The existence of such primary elements as these, which are supposed to form the basis of organization of the protoplasm of cells, as well as the physical basis of heredity, is insisted on by nearly all of the biologists who have written on this subject. Professor Whitman, in an able article entitled "The Inadequacy of the Cell Theory," states that Ernst Brücke in 1861 first contended for the organization of the cell, and the existence of "smallest parts" as the basis of this organization, quoting him as follows. "We must therefore ascribe to living cells, in addition to the molecular structure of the organic compounds which they contain, still another and otherwise complicated structure; and this it is that we designate by the name organization." (Elementarorganismen, p. 387. Wiener Sitzungsberichte, October 10, 1861, Band XLIV. Heft 2, p. 381.)

Whitman then goes on to say that "we have seen similar ideas reappear in the 'physiological units' of Herbert Spencer, the 'gemmules' of Darwin, the 'micellæ' of Nägeli, the 'plastidules' of Elsberg and Haeckel, the 'inotagmata' [plasomes] of Wiesner, the 'idioblasts' of Oscar Hertwig, and the 'biophores' of Weismann."

Whitman contends that the secret of organization, growth, development, lies not in cell formation, "but in those ultimate elements of living matter for which *idiosomes* seems to me an appropriate name." He adds: "All growth, assimilation, reproduction, and regeneration may be supposed to have their seat in these fundamental elements. They make up all living matter, are the bearers of heredity, and the real builders of the organism." (Journal of Morphology, VIII. 639, 658, Boston, 1893. Compare also Weismann's "The Germ Plasm," Introduction.) Here should be quoted the striking remark of Herbert Spencer, "that sperm cells and germ cells are essentially nothing more than vehicles in which are contained small groups of the physiological units in a fit state for obeying their proclivity towards the structural arrangement of the species they belong to." (Principles of Biology, I. 254.)

In his latest work Weismann * thus states his mature and apparently final views: "All the phenomena of heredity depend on minute vital units which we have called *biophors*, and of which living matter is composed; these are capable of assimilation, growth, and multiplication by division." (p. 450.) He further discusses the nature and mode of action of these hypothetical bodies, which are contained in the nucleus, the latter serving as the "bearer of the biophors controlling the character of the cell." How these biophors are grouped into *determinants*, and how the latter form aggregates called *ids*, the nuclear rods (chromosomes) being aggregates of ids, called *idants*, is set forth in a very circumstantial way. He then states in the summary of his work: "The *germ plasm*, or hereditary substance of the Metazoa and Metaphyta, therefore, consists of a larger or smaller number of idants, which in turn are composed of ids; each id has a definite and special architecture, as it is composed of determinants, each of which plays a perfectly definite part in development." (p. 453.)

Weisman's reasons for not accepting the doctrine of transmission of acquired characters would appear to be purely hypothetical and *a priori*, as will be seen by the following extracts: "It is self-evident from the theory of heredity here propounded that only those characters are transmissible which have been controlled — i. e. produced — by determinants of the germ, and that consequently only those variations are hereditary which result from the modification of several or many determinants in the germ plasm, and not those which have arisen subsequently in consequence of some influence exerted upon the cells of the body. In other words, it follows from this theory that *somatogenic or acquired characters cannot be transmitted*. This, however, does not imply that external influences are incapable of producing hereditary variations; on the contrary, they always give rise to such variations when they are capable of modifying the determinants of the germ plasm. Climatic influences, for example, may very well produce permanent variations, by slowly causing gradually increasing alterations to occur in certain determinants in the course of generations. An apparent transmission of somatogenic modifications may even take place under certain circumstances, by the climatic influence affecting certain determinants of the germ plasm at the same time, and when they are about to pass to that part of the body which they have to control. This is indicated by the climatic variations of the butterfly *Polyommatus phlæas*."

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* The Germ Plasm. A Theory of Heredity. Translated by W. N. Parker New York, 1893.

He then adds: —

"The primary cause of *variation* is always the effect of external influences. Were it possible for growth to take place under absolutely constant external influences, variation would not occur; but as this is impossible, all growth is connected with smaller or greater deviations from the inherited developmental tendency.

"When these deviations only affect the soma, they give rise to temporary non-hereditary variations; but when they occur in the germ plasm, they are transmitted to the next generation, and cause corresponding hereditary variations in the body." (pp. 462, 463.)

That the physical seat of heredity does exist in the nucleus has been wellnigh demonstrated, if not quite, by some remarkable experiments by Boveri at the Naples Zoölogical Station, so that what was a mere hypothesis has apparently become a matter of fact. Boveri's results appeared in 1889,* and a translation of his short paper has been published by Prof. T. H. Morgan in "The American Naturalist" for March, 1893.

Five years ago, by accident, the brothers Hertwig discovered that in consequence of shaking, certain eggs of sea-urchins fell to pieces; some of these pieces contained nuclei and others not. It was found that the non-nucleated pieces could be artificially fertilized as well as those containing nuclei, and that the bits of yolk underwent what is called segmentation.

Boveri, taking the hint suggested by these happy accidents, made the astonishing discovery that the enucleated bits of eggs could be fertilized, and that such bits developed into larvæ or young sea-urchins as completely formed as those growing from ordinary entire fertilized eggs.

The further experiments to prove the seat of heredity were to hybridize the fragments of eggs of one genus of sea-urchins with the sperm cells of another genus, and to rear them far enough along in life to determine whether the young showed the qualities of both species or one only. By cross fertilizing the enucleated egg fragments of Sphærechinus with the male germs of Echinus, Boveri produced an almost exact middle form, standing half-way between the two parents. He found however that a portion of the cross-bred larvæ agreed entirely with the simple ordinary larva of Echinus, which he thinks must have been produced chiefly from enucleated fragments. This seemed to be proved by the fact that he could distinguish in a preserved and colored larva whether or not it had originated from a nucleated or enucleated egg by the size of its nuclei, which are considerably smaller in the larvæ derived from the enucleated bits of eggs. Hence all doubt seemed removed, and Boveri claims that he has proved that, by cross fertilization of whole eggs or bits of eggs having nuclei, larvæ are formed that are half-way between the larval forms of the parent species. On the other hand, larvæ arising from the *enucleated* bits of eggs have entirely the characteristics of the parent (male) species. Hence, if his experiments are correct, he demonstrates the law that the nucleus alone is the bearer of hereditary qualities. Thus the hypothesis that the substance of the nucleus of reproductive cells is the physical basis of heredity seems provisionally at least placed on a foundation of fact.

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* Ein geschlechtlich erzeugter Organismus ohne mütterliche Eigenschaften. Sitzung der Gesellschaft für Morphologie und Physiologie zur München. Sitzung am 16 Juli, 1889.

On the other hand reference should be made to the recent papers of Driesch and of O. Hertwig,* who from researches on the phenomena of cleavage and the formation of organs in the embryo of the frog regard the egg as isotropic, its first cells as qualitatively alike, the development of the embryo being the result of an epigenetic formation of organs, the process being one of interrelation of the cleavage cells. Hence in place of the mosaic theory of Roux and the germ plasm theory of Weismann, Hertwig substitutes the theory of the controlling inter-adjustments of the embryonic cells and later of the tissues and organs.

II. HEREDITY OF CHARACTERS ACQUIRED DURING THE LIFETIME OF THE INDIVIDUAL.

It would appear that many, if not most, of our leading anatomists and cytologists agree that there may be a physical basis for heredity, and that this basis is afforded by the germ plasm of the nucleus, a portion of which is continuous in succeeding generations. They do however disagree as to whether acquired or "somatogenic" characters can be transmitted by heredity, and whether the contents of the nuclei of germ cells are influenced or not by whatever affects the body in general.

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* O. Hertwig, Archiv für Mikroskop. Anatomie, 22 December, 1893, XLII. 662–794. See Abstract by E. A. Andrews in the American Naturalist, March, 1892, pp. 272–278.

Perhaps the ablest objector to this phase of Weismann's theory of heredity is Kölliker,* who (1) denies that there is any fundamental difference between body and germ plasm; and (2) claims that in the various cellular changes the characters of the original germ plasm may be either wholly retained, or degenerate, or be wholly lost.

Sir William Turner † and other medical men also favor the theory of the transmission of acquired characters. He suggests that the more subtle processes of generation may be transmitted where mutilations may not.

Detmer ‡ likewise opposes Weismann's view on the following grounds: —

1. The intimate histological influences of external conditions on the organism.

2. The importance of correlation in allowing an influence to saturate from one part to another, and thus to the sexual cells.

3. The suggestiveness of the persistence of certain phenomena (in plants) after the inciting conditions have ceased.

The criticisms of Kölliker have been ably discussed by Weismann in his Essays upon Heredity.

The views which have had weight with us, and which seem to oppose Weismann's theory that acquired traits cannot be transmitted, are the following: —

1. The laws of correlation (*a*) of growth, and (*b*) of organs in the mature organism.

If one part or organ of the body is removed, aborted, or changed, the rest may, in certain cases, be either temporarily or permanently affected by the change.

2. Whatever affects the body in general would tend to affect the germ plasm, since the tissues and cells of the ovaries and testes are supplied with blood, and are innervated like other parts and organs of the body; hence the plasm of the nuclei of these cells, though it may exist in a temporarily indifferent state is nourished, or at least preserved from degeneration, and is thus influenced by whatever affects the body.

3. The operation of castration in either sex, as is well known, re-

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* Das Karyoplasma und die Vererbung. Zeitschrift für wissens. Zoologie, XL. iv. 228, 1886, and Anat. Anzeiger, III., 1888.

† Report of the British Association for the Advancement of Science for 1889, pp. 756-771. 1890.

‡ Zum Problem der Vererbung. Archiv für die ges. Physiologie, XL. 1887.

sults in a profound modification of the physical, intellectual, and moral nature of the subject operated upon.

4. It has not yet been satisfactorily disproved that new characters, or the tendency to the heredity of such characters, are not the result of a change of external environment, however slight. This appears to be the primary cause of all changes in organisms.

5. As blastogenic or congenital characters are not invariably transmitted, with much less reason may somatogenic or acquired characters be invariably transmitted, especially at the present day.

6. The transmission of acquired characters may have been more frequent and regular in early geological ages, during the period of the origin of family, ordinal, and class ancestral types, and when such forms were more plastic than now owing to more wide-spread and rapid changes in the physical geography of the earth's surface than occur at present. During palæozoic times somatogenic characters may have greatly preponderated over blastogenic characters; for at certain critical periods in geological history there were wide-spread extinctions of certain species of plants and animals, followed or accompanied by profound modification of others, which led to the origination of new types. Hence a study of the origin and subsequent modification and disappearances of organs in series of extinct animals will afford weighty facts.

7. If congenital characters are the only ones which can be inherited, they must have in the beginning originated from those acquired during the lifetime of the individual, or if not in the first, in the second or third, or a later generation.

8. Can we always draw the line between congenital and acquired characters? It seems to us to be often not only very difficult, but well-nigh impracticable, except in animals with a metamorphosis.

9. The results of the cultivation of fruits and of the domestication of animals, as well as the experiments of Brown-Séquard, Bert, and others, strongly suggest that the characters acquired during the lifetime of such organisms are capable of transmission.

10. If there were no such thing as the transmission of characters, either anatomical, physiological, or mental, originating during the lifetime of an organism, how should we have any evolution resulting in the different groups of organisms? Does not the denial of the fact of transmission of acquired features either in the past or present cut away the support for either phase of evolution, whether Lamarckism or Darwinism?

If the processes of heredity have to be begun over again with the birth of each individual, then we shall have to invent a new term for what is ordinarily understood to be progressive or continuous evolution. The assumed peculiar property of the germ plasm is its continuity from one generation to another, and its capability of receiving with each new generation the impress resulting from a change in the environment, or tendency to such change. Were this not so, then the offspring would be simply a repetition of the parents, instead of being like them with a difference, and there would be neither any fixed variation nor any individuality in organisms. Take the subject of human education. Does it wholly depend on the permanence of the intellectual enviroment, or is there an inherited capacity or aptitude for learning which runs in families or strains, and which is the result of the education of one or several generations, whether the training be for business, for the learned professions, or even for criminal pursuits? Unless we are much mistaken, all human progress in learning, or in the arts and sciences, is based on the conception that in the long run mankind will increase in mental intelligence and capacity for learning. The history of science shows that a new department of learning may arise and each succeeding generation work more easily on the foundation laid by the previous generation. The work does not have to be begun *de novo*, but some degree of capacity for the new cult is inherited by successive generations; certainly the intellectual environment may be said to change with each generation.

All progress in humanity appears to be due, not only, in the first place, to our maintaining the present intellectual environment, with the manifold and many-sided stimuli of our present social structure, but also to the unceasing efforts of the leaders in advanced thought in many different departments of mental training and effort to open up new fields of research in natural, physical, and mental science, and their applications, to gain new and higher points of view in sociology and morals as well as in statecraft, and in short to perfect and hasten the development of the ideal man. Unless this progress, which is an historic fact, has been due not only at the outset, but all through human history thus far, to this principle of the inheritance of mental traits, causing the intellectual efforts of one generation to pass down and thus to have finally a cumulative effect, how could there be any progress in human society? *

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* Herbert Spencer states in his Principles of Biology: "Certain powers which mankind have gained in the course of civilization cannot, I think, be accounted for, without admitting the inheritance of acquired modifications." Vol. I. p. 249.

On the one hand, let us imagine a cessation of the operation of this principle. Suppose all the forces and stimuli of modern society to be removed, and the human organism to live like blind beetles in a cave, or a savage tribe isolated in the midst of an otherwise uninhabited continent, with a total uniformity of conditions, physical, social, and moral, the effects of disuse would at once set in. Heredity without this vivifying principle of cumulative transmission, as it might be called, would be retrogressive in its action, and the race would by reversion return to the status of prehistoric times. Or, on the other hand, if the present intellectual environment were maintained without the cumulative action of the principle of inheritance of acquired characters, the social organism would become stagnant, and the race would be semi-fossilized, or in a state of arrested development, like the Chinese.

As we have already suggested in the beginning, blastogenic or acquired characters may have greatly preponderated over the somatogenic, and in fact the former or acquired characters may have constituted the fundamental elements of heredity in general when life forms had only got as far as the Monera and lowest Protophytes. Then as the life forms became more differentiated there may have ensued a corresponding specialization into both blastogenic and somatogenic characters. It seems most probable, as Kölliker suggested, that there is no fundamental difference between the body and germ plasm, and such a difference if it exists may be incapable of physical demonstration.

Apropos of the view that whatever affects the body in general must have some effect, however slight, on the germ plasm in it, we would cite the following facts and considerations.

Mr. Herbert Spencer in a powerful article in the Contemporary Review for March, 1893, entitled "The Inadequacy of 'Natural Selection,'" after quoting the facts regarding Lord Morton's hybrid between a male quagga and a chestnut mare seven eighths Arabian, and the results of crossing English and French breeds of sheep, and Giles's "sow and her produce," as fatal to Weismann's theory of the non-transmission of acquired characters, contends that these facts demonstrate "that the somewhat different units of a foreign germ plasm permeating the organism permeate also the subsequently formed reproductive cells, and affect the structures of the individuals arising from them."

He then quotes Professor Sedgwick's letter to himself, dated December 27, 1892, referring to the continuity of the cells composing the tissues of animals, so that the protoplasm of the whole body is continuous, in which he states "that the connections between the cells of adults are not secondary connections, but primary, dating from the time when the embryo was a unicellular structure." Hence Spencer maintains that "the alleged independence of the reproductive cells does not exist." Thus the *soma* is a "continuous mass of vacuolated protoplasm, and the reproductive cells are nothing more than portions of it separated some little time before they are required to perform their functions."

In his "Monograph of the Development of Peripatus Capensis," Mr. Adam Sedgwick, F. R. S., Reader in Animal Morphology at Cambridge, writes as follows: —

"All the cells of the ovum, ectodermal as well as endodermal, are connected together by a fine protoplasmic reticulum." (p. 41.)

"The continuity of the various cells of the segmenting ovum is primary, and not secondary; i. e. in the cleavage the segments do not completely separate from one another. But are we justified in speaking of cells at all in this case? *The fully segmented ovum is a syncytium, and there are not and have not been at any stage cell limits.*" (p. 41.)

He then states in his letter to Mr. Spencer: —

"It is becoming more and more clear every day that the cells composing the tissues of animals are not isolated units, but that they are connected with one another. I need only refer to the connection known to exist between connective tissue cells, cartilage cells, epithelial cells, etc. And not only may the cells of one tissue be continuous with each other, but they may also be continuous with the cells of other tissues." (pp. 47, 48).

"Finally, if the protoplasm of the body is primitively a syncytium, and the ovum until maturity a part of that syncytium, the separation of the generative products does not differ essentially from the internal gemmation of a Protozoön, and the inheritance by the offspring of peculiarities first appearing in the parent, though not explained, is rendered less mysterious; for the protoplasm of the whole body being continuous, change in the molecular constitution of any part of it would naturally be expected to spread, in time, through the whole mass." (p. 49.)

"Mr. Sedgwick's subsequent investigations confirm these conclusions. In a letter of December 27, 1892, passages which he allows me to publish run as follows: —

"'All the embryological studies that I have made since that to which you refer confirm me more and more in the view that the connections between the cells of adults are not secondary connections, but primary, dating from the time when the embryo was a unicellular structure. . . . My own investigations on this subject have been confined to the Arthropoda, Elasmobranchii, and Aves. I have thoroughly examined the development of at least one kind of each of these groups, and I have never been able to detect a stage in which the cells were not continuous with each other; and I have studied innumerable stages from the beginning of cleavage onwards.'"

As regards plants, De Vries * and other botanists believe that all or the greater number of cells in the plant body contain the total heredity characters of the species in a latent condition.†

In this connection should be noted an observation of Maupas, who saw the cytoplasm of an infusorian pouring into the nucleus until its bulk was increased eight times.

Hoffman observed the transmission of acquired characters in the poppy, etc., as the result of deficient nutrition.‡

In 1890 Van Bemmelin § gave a useful and very exhaustive account of the doctrine of heredity, with especial reference to the question of heredity of acquired characters, stating the views of various pathologists, anthropologists, and physiologists. In conclusion he makes some objections to the view that the germ plasm is independent of external influences.

I am indebted to Prof. G. W. Field for the statement that MM. Charrin and Phisalix ‖ cultivated *Bacillus pyrocyaneus* for several successive generations at 42.5° C. with the result that it lost its chromogenic property. This non-chromogenic character apparently thus acquired was retained upon cultivation under most favorable circumstances, and it seemed to show no tendency to recover the chromogenic property.

"Laurent modified the chromogenic function of the Kiel water bacillus by exposing it to direct sunlight for a limited time. The suppression of this peculiarity was transmitted from generation to generation, so that a perfect albinotic variety was formed. The color property was also lost when cultivated at blood heat, and was not regained when continued cultivation was carried on at lower temperatures." *

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* Intracellülare Pangenesis, Jena, 1889.

† Osborn, *loc. cit.*, p. 62.

‡ Biol. Centralblatt, 1887, p. 667; Botan. Zeitung, 1887, pp. 260, 772, 773.

§ De Erfelijkheid van verworven Eigenschappen. 's Gravenhage. p. 279. (See abstract by V. Haecker in Biolog. Centralblatt, Bd. X. pp. 641–652, 686–694. Also a brief abstract in Zoologischer Jahresbericht für 1890, Alg. Biologie u. Entwick., p. 23.)

‖ See Comptes Rendus, 1892, CXIV. 1565–1568.

In still more recent experiments Gley and Charrin † have vaccinated a certain number of male rabbits against the effects of the bacillus of blue pus (*Bacillus pyocyaneus*) by injecting into them attenuated cultures. These males then mated with females while in heat. The greater number of the offspring died before birth or soon after; those which lived were atrophied, more or less deformed, but in some cases endowed with an immunity from the effects of the bacillus of blue pus.

"It is evident," says Cuénot, in commenting on this experiment, "that the attenuated infection communicated to the fathers by vaccination had profoundly deranged the structure of the male germ plasm; hence the numerous abortions and malformations of their descendants. It is exactly the same as in the case of females alone which have before fecundation received injections of poisons; they either abort, or the young do not grow and die at an early age."

That the effects of alcoholism and other forms of intoxication with poisons, etc., produced on individuals are inherited by the next generation is allowed by M. Cuénot. Whether the effect upon the system saturates through and affects the germ plasm or not does not affect the fact that such lesions are acquired during the lifetime of the individual. As he says: —

"Intoxication of the organism which is not fatal likewise reacts on the germ plasm, which may undergo profound modifications. Alcoholism, for example, which exaggerates in a way so characteristic the diatheses of parents (insanity, cirrhosis, etc.) also alters the sexual cells. The children of parents both affected with alcoholism, when born, are sickly, unhealthy, presenting a special predisposition to consumption and to nervous troubles."

It is possible, adds Cuénot, that the celebrated observations of Brown-Séquard, confirmed by Dupuy and Obersteiner, on the heredity of epilepsy produced in guinea-pigs, is also explained by a partial intoxication of the germ plasm. The guinea-pigs are rendered epileptic by different procedures, i. e. section of the spinal cord, of the sciatic nerve, of the great sympathetic, etc. The young to which they give birth after these operations often present (17 times in 30) a general feebleness, and various nervous affections; motor paralysis of the fore or hind legs, or trophic paralyses, which result in the loss of toes, of the cornea, etc.;* in 32 young born of epileptic parents two have shown symptoms of epilepsy. "The transmission of nervous troubles cannot then leave the shadow of a doubt, although in no case has *the mutilation which has been the cause of it in the parents been reproduced in the descendants.*" Cuénot then adds, "We are still in the presence of an infection of the germ plasm, due perhaps to bacteria as in the case of syphilis (an opinion sustained with much force by Weismann), perhaps also to poisons secreted by epileptic parents, which carries us back to the case of alcoholism."

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* Bacteriology in its General Relations. By H. L. Russell. Amer. Naturalist, December, 1893, p. 1060.

† Gley et Charrin, Influences héréditaires expérimentales. Comptes Rendus de l'Académie des Sciences, Paris, CXVII., 1893. Quoted from L. Cuénot in "Revue gen. des Sciences, pures et appliquées," 15 Fév., 1894. This and other cases are cited by M. Cuénot in favor of Weismannism, but we think they directly prove the contrary; they illustrate the direct action of a change of environment during the lifetime of the individual, the changes being inherited by the succeeding generation.

Another case is the result of experiments by Paul Bert,† who attempted to acclimatize some Daphniæ in salinated water by adding from day to day a little salt in the water of an aquarium. At the end of 45 days, when it contained 1.5% of salt, all the Daphniæ had died, but the *eggs contained in their brood-sac survived,* and the new generation of Daphniæ to which they had given birth flourished perfectly well in the same medium. "This experiment," adds Cuénot, "shows with admirable clearness that the germ plasm has, owing to the modification, become accustomed to the salt, causing it to produce a generation so different from the preceding." We should interpret these facts as showing that the Crustacean had been so profoundly affected in the lifetime of the individual as to produce young perfectly adapted to a changed environment; the germ plasm may have been the vehicle, all the same, but the experiment is a case in favor of the Neo-Lamarckian principle.

Other authors who have advocated the views that acquired characters may be transmitted are Cope,‡ Ryder,§ Osborn, Vines,‖

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* It appears that, if the young are born with tails, an even more important lesion, the loss of toes and of the cornea, etc., results. Why should not these cases strongly confirm the Lamarckian principle of the inheritance of characters acquired during the lifetime of the individual?

† P. Bert, Sur la Cause de la Mort des Animaux d'Eau douce qu'on plonge dans l'Eau de Mer. Comptes Rendus de l'Académie des Sciences, XCVII., Paris, 1883.

‡ Origin of the Fittest, 1887, and minor papers.

§ A Physiological Hypothesis of Heredity and Variation. Amer. Naturalist, January, 1890, pp. 85–92.

‖ Lectures on the Physiology of Plants. Cambridge, 1886.

Eimer,* Geddes and Thompson,† Brown-Séquard,‡ and Giard,§ as well as Henslow, Lloyd Morgan, and others.

Eimer's work is entirely based on the view that the inheritance of acquired characters is a fundamental law of organic growth, though he allows "that the permanent action of external conditions on the body of the organism in most cases is not immediately perceptible. From physiological principles this is not in general possible." He thinks that more time than even Darwin supposed to be necessary must be invoked. He adds: "Every character which must have been formed through the activity of the organism is an acquired character. All characters, therefore, which have been developed by exertion, are acquired, and these characters are inherited from generation to generation. The same holds for all organs atrophied through disuse; the degree of atrophy is acquired and inherited. In the first class we see especially the action of direct adaptation, in the second the results of the cessation of this action. A third class of acquired characters are to be traced simply to the immediate action of the environment on the organism, and originally, at the commencement of their appearance, all characters must have belonged to this class." (p. 87.)

At present it seems the better course, now that the hypothesis has been so fully discussed, to wait for more facts, and to very thoroughly test the cases which seem to favor or to oppose the doctrine.

Some of the discussions held on this subject have savored of the metaphysics of the Middle Ages, and quite artificial distinctions, with the invoking of "natural selection" by authors whose natural selection is quite a different doctrine from the natural selection of Darwin; and other occult causes have been given undue prominence.

Meanwhile we feel justified from the facts now known in holding the view that characters acquired in the lifetime of the individual, as the result of functional activity in certain regions of the body or in certain organs, may under favorable conditions be more or less completely transmitted; or at least the tendency to such transmission, if latent in one generation, may appear in a succeeding one. And in the earlier geological ages this principle may have been much more active than at present. The hypothesis seems to be a good working one to account for phenomena which cannot be otherwise explained, and should not in consequence of adverse, though often very able and candid criticism, be set aside. On the contrary, if as the result of Weismann's criticisms it be only provisionally adopted, should it not lead to further experiments in the laboratory, and to further and more thorough studies of the metamorphosis of animals, with a view to ascertain how far they are correlated with changes of habit and function?

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* Organic Evolution as the Result of the Inheritance of Acquired Characters, etc. Translated by J. T. Cunningham. London, 1890.

† Evolution of Sex, 1890. See also Dr. O. von Rath's Criticisms of some Cases of Apparent Transmission of Mutilations. Translated by Prof. H. B. Ward, Amer. Naturalist, with the bibliography at the end of the article, January, 1894.

‡ Faits nouveaux établissant l'extrême Fréquence de la Transmission par Hérédité d'États organiques morbides, produits accidentellement chez des Ascendants. (Comptes Rendus de l'Académie des Sciences, 13 Mars, 1882.)

§ L'Hérédité des Modifications somatiques. Revue Scientifique, Tom. XLVI. No. 23, 6 Déc., 1890.

The lines of future investigation in this field appear to lie mainly in four directions: —

1. In the domain of comparative cytology.
2. In the study of the life histories or metamorphoses of animals.
3. In the further observation of the facts of heredity as observed in the raising of plants, in the breeding of domestic animals, and that of the different races of mankind, and especially by laboratory experiments like those of Semper, Bert, and others, in changing the surroundings of organisms.
4. In the study of the gradual modification and specialization of some organs in forms now extinct, with the degeneration and loss of others, a subject so fully worked out by Professor Osborn as regards the teeth of mammals.

III. INHERITANCE AT CORRESPONDING PERIODS OF LIFE.

But perhaps the crucial cases will be found to occur in animals with a complicated metamorphosis, because in such instances we can draw the line between characters which are congenital and those which are acquired. As regards the characters which appear in post-embryonic life, it is not difficult to see that they have originated in response to stimuli brought about by changes in the environment.

My attention has been turned to this subject while studying the complicated life histories of some of the Bombycine moths, in which there are usually five distinct larval stages, and sometimes as many as nine, not to mention the pupal and imaginal stages. Now in each and all of these stages the organism is as a rule adapted to some more or less temporary change in its environment. It seems, the more closely we observe the habits of some of these caterpillars, almost capable of demonstration that the different temporary colors, markings, organs, and structures developed, and for the time being useful only to become at a later stage useless and therefore discarded, as new and dissimilar conditions of life arose, — it seems almost self-evident that such markings and structures were the result of the responses of an organism in its most plastic time of life to changes in its habits, such changes being due either to changes in its surroundings, or to the effort to repel the attacks of insects, birds, etc.

However such stages arose, they are at the present epoch transmitted from parent to offspring with wonderful certainty. Among the Arctians, and in other caterpillars, the number of moults is known to vary, either from artificial breeding or from other unknown causes, possibly lack of nutrition. This form of heredity was called by Darwin* "Inheritance at corresponding Periods of Life," and by Haeckel† "Homochronous Transmission." Darwin thus describes the phenomenon: "When the embryo leads an independent life, that is, becomes a larva, it has to be adapted to the surrounding conditions in its structure and instincts, independently of those of its parents; and the principle of inheritance at corresponding periods of life renders this possible." (p. 51.) Again: "On this principle of inheritance at corresponding periods, we can understand how it is that most animals display from the germ to maturity such a marvellous succession of characters." (p. 60.)

Examples of this law are the complicated metamorphosis of certain free, but more especially the parasitic worms, notably the fluke worms and the Cestodes, the complicated metamorphoses of the Echinoderms, of the Mollusca, the Crustacea, and the metamorphic insects, and more especially such insects as the Meloidæ, Rhipiphoridæ, and Stylopidæ, in which there is a hypermetamorphosis.

It is not altogether improbable that the phenomena of alternation of generations is primarily due to changes in surroundings, and hence of habits, resulting in new needs which were met by adaptation to the new surroundings, the different stages being finally fixed by homochronous heredity. Take the case of the Hydroids, where the generation of fixed hydra-like individuals gives rise by budding to the free-swimming, egg-producing medusa form. The hydra-like individuals are the result of direct inheritance, while the medusa is probably a secondary product, the result of adaptation to a free-swimming mode of life; all its organs in a so much higher scale of perfection than those of the generalized hydra-form ancestor having resulted from the manifold stimuli of a changeable environment. The same may be said of the Aurelia, with its free Scyphistoma larval stage.*

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* The Variation of Animals and Plants under Domestication, II. 51.

† History of Creation, I. 217, 218. See also Giard, who, referring to the laws of heredity, remarks: "Plusieurs de ces lois, et en particulier la loi de l'hérédité homochrone, fournissent aussi, nous le verrons, de bons arguments en faveur du principe de Lamarck." Revue Sc., 6 Déc., 1890.

The alternation of generations in the Trematodes is apparently likewise the result of adaptation to a change of hosts bringing about homochronous heredity. It is evident that alternation of generations is the extreme of a series, beginning (1) with simple direct growth; (2) an incomplete metamorphosis (the lower winged insects); (3) genuine metamorphosis; (4) the hypermetamorphosis of Meloidæ, Rhipiphoridæ, and Stylopidæ; the 5th and last term being the cases of alternation of generations. It seems difficult to account for these sets of individuals or generations, unless we resort to the principle of inheritance of characters acquired during the lifetime of the ancestral forms, which gave rise to these interrupted or alternate series of forms.

On the other hand Weismann in order to account for alternation of generations carries us out of the sphere of observation and induction into speculative regions, and assumes that "*two kinds of germ plasm exist in those species in which alternation of generations occurs*, both of which are present in the egg cell as well as in the bud, though only one of them is active at a time and controls ontogeny, while the other remains inactive. The alternating activity of these two germ plasms causes the alternations of generations." † Are not over-nutrition and changes in station and habits the more appreciable and potent causes?

The complicated metamorphosis of the Crustacea is the result of the adaptation to variations in the environment. It is not improbable that the Nauplius of the primitive Crustacea, the Branchiopoda (including the Phyllopoda), was a secondary and not a primary form. The proof would seem to be the non-existence of any adult Arthropod with such a form and structure as that of the Nauplius. The earliest Crustacean was probably a naked, shelless Cladoceran or Phyllopod-like form, with a few or many definite segments, bearing unjointed or imperfectly jointed lamellate swimming legs, derived from the flattened parapodia of some ancestral Annelid worm. The cylindrical rowing appendages of the Nauplius appear to be secondary and adaptive characters, fitting it for its free-swimming surface life.

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* In his suggestive book entitled "A Theory of Development and Heredity" (1893), Prof. H. B. Orr accounts for alternation of generations by secondary changes of the environment which favored the hydroid stage and the perfect medusa stage, and at the same time tended to eliminate the intermediate stages. In other cases the secondary changes of environment destroyed the hydroid stage, as we find Medusæ without any hydroid stage. (p. 225.)

† The Germ Plasm, p. 457.

The Zoëa larva of the Decapoda, with its body composed of head and abdomen alone, without thoracic segments and appendages, is also an adaptive stage, a differentiated or farther advanced Nauplius.

The Megalops stage of the Brachyura, or crabs, induced at the end of the free-swimming life of the zoëa, and intermediate between the zoëa and crab stage, the thorax and thoracic appendages being present, is likewise an adaptation to the transition period connecting the free-swimming or surface life and the creeping and bottom life of the adult.

These different stages, the result of adaptation, are signal examples of the inheritance of characters at corresponding periods of life, and would appear to have been originally the result of the inheritance of characters originated or acquired during the life of the individual; i. e. the ancestor of the existing decapodous Crustacea.

On the other hand, in groups where a metamorphosis is the rule, there are exceptional forms in which development is abbreviated or direct. Such cases are the direct development of the starfish, *Leptychaster kerguelenensis* Smith, while *Pteraster militaris* is viviparous; and the direct development of *Anochanus sinensis* and of *Hemiaster cavernosus* among Echinoids. The lobster and crayfish are exceptions to other macrurous Crustacea, in which there is a complicated metamorphosis, their development being condensed or abbreviated, and limited to embryonic life. So with the crabs of several species living in the Black Sea, whose direct development was traced by Rathke.

In such exceptional cases as these, the phenomenon of direct development will undoubtedly be found to be caused by some change in the conditions of existence.

Attention should also be here drawn to the fact that the term congenital is an elastic one. Mammals, at least the placental ones, are only born after a long uterine life, but fish and tadpoles, as well as the higher nesting birds, are born in a more premature condition, and congenital characters in these animals have quite a different significance from those of mammals. So it is in a less degree with the larvæ of insects, the degree of inequality in the perfection of the larva being very great in different groups, especially in the parasitic Hymenoptera and Coleoptera.

IV. HOMOCHRONOUS HEREDITY IN INSECTS WITH A HYPERMETAMORPHOSIS.

The hypermetamorphoses of the Meloidæ, Rhipiphoridæ, and Stylopidæ very strikingly illustrate the principle we are endeavoring to emphasize and establish. The facts are given in the writings of Newport, Fabre, Westwood, Siebold, Valery-Mayet, Riley, and others.

In Meloë the freshly hatched larva, or "triungulin," is an active Campodea-like larva, which runs about and climbs up flowers, from which it creeps upon the body of bees, such as Anthophora, who carries it to her cells, wherein her eggs are situated. The triungulin feeds upon and destroys the eggs of its hostess. Meanwhile its inactive life in the bee's cell reacts upon the organism; after moulting, the second larval form is attained, and now the body is thick, cylindrical, soft, and fleshy, and it resembles a lamellicorn larva, with three pairs of rather long thoracic legs. This second larva feeds upon the honey stored up for the young or larval bees. After another moult, there is another entire change in the body; it is motionless, the head is mask-like without movable appendages, and the feet are represented by six tubercles. This is called the semi-pupa or pseudo-pupal stage. This form moults, and changes to a third larval form, when apparently, as the result of its rich concentrated food, it is overgrown, thick-bodied, without legs, and resembles a larval bee.

After thus passing through three larval stages, each remarkably different in structure and in the manner of taking food, it transforms into a pupa of the ordinary coleopterous shape.

The history of Sitaris, as worked out by Fabre and more recently by Valery-Mayet, is a similar story of two strikingly different adaptational larval forms succeeding the triungulin or primitive larval stage. The first larva is in general like that of Meloë, the second is thick, oval, fleshy, soft-bodied, and with minute legs, evidently of no use, the larva feeding on the honey stored by its host. The pseudo-pupal stage is still more maggot-like than in the corresponding stage of Meloe, and the third larva is thick-bodied, with short thoracic legs.

In the complicated life history of another Cantharid, *Epicauta vittata*, as worked out by Dr. C. V. Riley, we have the same acquisition of new habits and forms after the first larval stage, which evidently were at the outset the result of an adaptation to a change of food and surroundings. The female Epicauta lays its eggs in the same warm, sunny situation as that chosen by locusts (Caloptenus) for depositing their eggs. On hatching, the active minute carnivorous triungulin, ever on the search for eggs, on happening upon a locust egg gnaws into it, and then sucks the contents. A second egg is attacked and its contents exhausted, when, owing to its comparatively inactive habits and rich nourishing food after a period of inactivity and rest, the skin splits along its back, and at about the eighth day from beginning to take food the second larva appears, with much smaller and shorter legs, a much smaller head, and with reduced mouth-parts. This is the Carabidoid stage of Riley. After feeding for about a week in the egg a second moult occurs, and the change of form is slight, though the mouth-parts and legs are still more rudimentary, and the body assumes "the clumsy aspect of the typical lamellicorn larva." This Riley denominates the Scarabæidoid stage of the second larva.

After six or seven days there is another transformation, the skin being cast, and the insect passes into another stage, "the ultimate stage of the second larva." The larva, immersed in its rich nutritious food, grows rapidly, and after about a week leaves the now addled and decaying locust eggs and burrows into the clear sand, where it lies on its side in a smooth cell or cavity, and where it undergoes an incomplete ecdysis, the skin not being completely shed, and assumes the semi-pupa stage, or coarctate larval stage of Riley.

In the spring the partly loose skin is rent on the top of the head and thorax, and then crawls out of it the "third larva," which only differs from the ultimate stage of the second larva "in the somewhat reduced size and greater whiteness." The insect in this stage is said to be rather active, and burrows about in the ground, but food is not essential, and in a few days it transforms into the true pupa state.

These habits and the corresponding hypermetamorphosis are probably common to all the Meloidæ, though the life history of the other species has yet to be traced.

In the genus Hornia described by Riley, the wings of the imago are more reduced than in any other of the family, both sexes having the elytra as rudimentary as in the European female glow-worm (*Lampyris noctiluca*). These, with the simple tarsal claws and the enlarged heavy abdomen, as Riley remarks, "show it to be a degradational form."

Its host is Anthophora, and the beetle itself lives permanently in the sealed cells of the bee, and Riley thinks it is subterranean, seldom if ever leaving the bee gallery. The triungulin is unknown, but the ultimate stage of the second larva, as well as the coarctate larva, is like those of the family in general, the final transformations taking place within the two unrent skins, in this respect the insect approaching Sitaris.

It appears, then, that as the result of its semi-parasitic mode of life the Campodea-form or triungulin larva of these insects which have free biting mouth-parts like the larvæ of Carabidæ and other carnivorous beetles, instead of continuing to lead an active life and feed on other insects, living or dead, and then like other beetles directly transforming into the normal pupa, moult as many as five times, there being six distinct stages, before the true pupal stage is entered upon. So that there are in all eight stages including the imaginal or last stage.

One cannot avoid drawing the very obvious conclusion that the five extra stages, constituting this hypermetamorphosis, as it is so well styled, were structural episodes, so to speak, due to the peculiar parasitic mode of life, and were evidently in adaptation to the remarkable changes of environment, so unlike those to which the members of other families of Coleoptera, the Stylopidæ excepted, have been subjected. The fat overgrown body and the atrophied limbs and mouth-parts are with little doubt due to the abundant supply of rich food, the protoplasm of the egg of its host, in which the insect during the feeding time of its life is immersed. Since it is well known that parthenogenesis is due to over, or at least to abundant nutrition, or to a generous diet and favoring temperature, there is little reason to doubt that the greatly altered and abnormally fat or bloated body of the insect in these supernumerary stages is the result of a continuous supply of rich pabulum, which the insect can imbibe with little or no effort.

The life history of the Stylopidæ is after the same general fashion, though we do not as yet know many of the most important details. The females are viviparous, hatching within the body of the parent, as I once found as many as 300 of the very minute triungulin larvæ issuing in every direction from the body of what I have regarded as the female of *Stylops childreni* in a stylopized Andrena caught in the last of April. The larvæ differ notably from those of the Meloidæ in the feet being bulbous and without claws, yet it is in general Campodea-like and in essential features a triungulin. The intestine ends in a blind sac, as in the larvæ of bees. and this would indicate that its food is honey. The complete life history of no Stylopid is completely known. It is probable that, hatched in June from eggs fertilized in April, the larvæ crawl up on the bodies of bees and wasps; finally, after a series of larval stages as yet unknown,* penetrating within the abdomen of its host before the latter hibernates, and living there through the winter. The females, owing to their parasitic life, retain the larval form, while the free males are winged, not leading in the adult stage a parasitic life, though passing their larval and pupal stages in the body of their host, and are so unlike ordinary beetles as to be referred by good authorities to a distinct order (Strepsiptera).

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* Westwood in his excellent account of this group remarks " Hence, as well as from the account given by Jurine, it is evident that the pupa of the Stylops is enclosed in a distinct skin, and is also in that state enveloped by the skin of

The triungulin stage of these insects corresponds in general to the form of the larval Staphylinidæ and allied families, such as the Tenebrionidæ, which are active in their habits, running about and obtaining their food in a haphazard way, often necessarily suffering long fasts. In these external-feeding, less active coleopterous larvæ, like the phytophagous species, which have an uninterrupted supply of nutritious food, we see that the body is thick and fleshy. So also in the larvæ of the Scarabæidæ, Ptinidæ, and the wood-boring groups. In internal feeders, like the larval weevils and Scolytidæ, which live nearly motionless in seeds, fruits, and the sap-wood of plants and trees, with a constant supply of nourishing, often rich food, the eruciform body is soft, thick, and more or less oval-cylindrical. So it is with the larvæ of Hymenoptera, especially in the parasitic forms, and in the ants, wasps, and bees, which are nearly if not quite motionless, at least not walking about after their food.

Now the change from the active triungulin stage to the series of secondary nearly legless, sedentary, inactive stages is plainly enough due to the change of station and to the change of food. From being an independent, active, roving triungulin, the young insect becomes a lodger or boarder, fed at the expense of its host, and the lack of bodily exertion, coupled with the presence of more liquid food than is actually needed for its bare existence, at once induces rotundity of body and a loss of power in the limbs, followed by their partial or total atrophy.

That this process of degeneration may even occur in one and the same stage of larval existence is very well illustrated by what we know of the life history of the wasp parasite of Europe, *Rhipiphorus paradoxus*. Thanks to the very careful and patient observations of Dr. T. A. Chapman, we have a nearly complete life history of this beetle, the representative of a family in many respects connecting the Meloidæ and Stylopidæ.* Where Rhipiphorus lays her eggs is un-

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the larva, contrary to the suggestion of Mr. Kelly." Class. Insects, II. 297. This is all we know about the supernumerary larval stages.

* Some Facts towards a Life History of Rhipiphorus paradoxus. Annals and Magazine of Natural History for October, 1870.

known. Dr. Chapman however found a solitary specimen of the young larva in the triungulin stage. He describes it as "a little black hexapod, about $\frac{1}{50}$ inch (.5 mm.) in length, and $\frac{1}{125}$ inch in breadth, broadest about the fourth segment, and tapering to a point at the tail; a triangular head with a pair of three-jointed antennæ nearly as long as the width of the head, with legs very like those of *Meloë* larvæ; the tibiæ ending in two or three claws, which are supported and even obscured by a large transparent pulvillus or sucker of about twice their length; this was marked by faint striæ radiating from the extremity of the tibiæ, giving it much the aspect of a lobe of a fly's proboscis. Each abdominal segment had a very short lateral spine pointing backwards; the last segment terminated by a large double sucker similar to those of the legs; and the little animal frequently stood up on this, and pawed the air with its feet, as if in search of some fresh object to lay hold of."

This almost microscopic larva finds a wasp grub and bores into its body, probably entering at a point near the back of the first or second segment behind the head. Dr. Chapman succeeded in finding the larva of the beetle within that of the wasp, before the latter had spun up. "Assuming that the wasp larva lives six days in its last skin before spinning up, I should guess that the youngest of these had still two or three days' feeding to do. The *Rhipiphorus* larvæ were but a little way beneath the skin of the back, about the fourth and fifth segments [counting the head as the first], and indifferently on either side. The smallest of these was $\frac{1}{16}$ inch in length, and, except its smaller size, was precisely like the larger ones I am about to refer to, having the same head, legs, plates, etc. These were of the same size as those of the larger larvæ, the difference in size of the latter being due to the expansion of the intermediate colorless integument."

After the wasp grub has spun the silken covering of its cell the larva of Rhipiphorus may be still detected in some of them, being rendered visible by its black legs and dark dorsal and ventral plates. "On extracting this larva, it bears a general resemblance in size and outline to the youngest larva of Rhipiphorus that I had found feeding externally on the wasp grub, but with the very notable exception of the already mentioned black marks. These are, in fact, a corneous head, six-jointed legs, and a dorsal and ventral series of plates. I immediately recognized the head and legs as identical with those of the little black mite already described, but presenting a ludicrous appearance in being widely separated from each other by the white skin of the larva. I have no doubt that the dorsal and ventral series of black marks are the corresponding plates of the mite-like larva floated away from each other by the expansion of the intervening membrane. By measurement also they agree exactly in size, although the larva extracted from the wasp grub is ten times the length and six times the width of the little *Meloë*-like larva. In length it is $\frac{1}{6}$ inch (4.5 mm.) and $\frac{1}{23}$ inch in breadth."

The remarkable changes thus described in the larva of this beetle after it has begun its parasitic life within the body of its host are especially noteworthy because the great increase in size and difference in shape, as well as in habits, all take place before the insect has moulted. The rapid development in size, and consequent distention of the body and the separation of the sclerites of the segments behind the head, are paralleled, as Chapman says, by the greatly swollen abdominal region of the body in *Sarcopsylla penetrans* and in the female of the Termitidæ. In those insects this distention is due to the enlargement of the ovaries and of the eggs contained within them, but in the Rhipiphorus it is due to the comparative inactivity of the larva, and to its being gorged with an unending supply of rich food, the blood and fat of its host. It follows, then, that if a sedentary life, and over, or at least abundant nutrition, will have this effect within the short period covered by the single first larval stage of the Rhipiphorus, it is reasonable to infer that the hypermetamorphosis is also due to the same factors.

Chapman then goes on to say, that finally, within six hours of the time of spinning up of the wasp grub, the Rhipiphorus larva at the end of Stage I., which is "usually in motion, and for its situation might be called tolerably active, is seen to lay hold of the interior of the skin with its anterior legs, and keeps biting and scratching with its strong and sharp jaws until it is able to thrust through its head, when, in less than a quarter of an hour, it completely emerges by a vermiform movement; and at the same time it casts a skin, together with the black head, legs, plates, etc."

The larva, now in its second stage, passes forward and seizes hold of the upper or lateral aspect of the prothoracic segment of the wasp grub. On emerging it becomes shorter and thicker, "and very soon loses length by that curving forward of its head which is so marked in the full-grown larva, and which does not exist before its emergence." The larva is now found "lying like a collar immediately under the head of the wasp grub, and is attached to it by the head, though not very firmly. At this stage the feeding of the young Rhipiphorus is rather sucking than eating.

When about 6 mm. in length it moults a second time, and the full-grown larva closely though superficially resembles a Crabro or Pemphredon larva, the small head being bent over forwards. By the time it is ready to pupate it has wholly eaten the wasp larva, and the temperature of the cell being high, a larva 5 mm. long grows large enough in two days to fill the top of the cell of its host, and the larva is ready to pupate about a week after hatching, so that its development is very rapid. The beetles themselves do not live in the cells. Chapman thinks they hibernate, and that the eggs are laid in the spring or summer.

We thus have in this insect three larval stages, the triungulin, and two later stages, the great differences between the first and the last two being apparently due to their parasitic mode of life, the larva spending its second stage within its host, involving an existence in a cell with a high temperature, an uninterrupted supply of rich, stimulating food, and a comparatively sedentary mode of life compared with that of the triungulin at the beginning of its existence. It is quite obvious that the hypermetamorphosis is primarily due to a great change in its surroundings, i. e. the parasitic mode of life of the beetle, habits of very rare occurrence in the Coleoptera, numerous in species as they are.

In the Proctotrypidæ there is also a hypermetamorphosis.*

In a species of Platygaster which is parasitic in the larva of Cecidomyia, the first larva (Cyclops stage) is of a remarkable shape, not like an insect, but rudely resembling a parasitic Copepod crustacean. In this condition it clings to the inside of its host by means of its hook-like jaws, moving about, as Ganin says, like a Cestodes embryo with its well known six hooks. In this stage it has no nervous, vascular, or respiratory system, and the digestive canal is a blind one.

After moulting the insect entirely changes its form, it is thick oval cylindrical, nearly motionless, with no appendages, but with a digestive canal and a nervous and vascular system.

After a second moult the third and last larval stage is attained, and the insect is of the ordinary appearance of ichneumon larvæ.

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* Metschnikoff, Embryologische Studien an Insecten. Zeitschrift für wissens. Zoologie, XVI. 389–500, 1866.

Ganin, Beiträge zur Erkenntniss der Entwickelungsgeschichte bei den Insecten. Zeitschrift für wissens. Zoologie, XIX. 381–451, 1869.

Ayers, On the Development of Œcanthus niveus and its Parasite, Teleas. Memoirs Bost. Soc. Nat. Hist., III. 225–281, 1884.

For an abstract of the work of Ganin, see Balfour's Comparative Embryology, I. 345–348; also Packard's Our Common Insects, 1873, pp. 161–167.

Not less striking is the life history of Polynema, which lays its eggs in those of a small dragon-fly (*Agrion virgo*). The first larval stage is most remarkable. It hatches as a microscopic immovable being, entirely unlike any insect, with scarcely a trace of organization, being merely a flask-shaped sac of cells. After remaining in this state five or six days it moults.

The second stage, or Histriobdella-like form, as Ganin names it, is more like that leach-like worm than an insect.

The third larval form is very bizarre, though more as in insects, having rudimentary antennæ, mouth-parts, legs, and ovipositor. In this condition it lives from six to seven days before pupating.

The strange history of another egg parasite (Ophioneurus) agrees in some respects with that of the foregoing forms. It is when hatched of an oval shape, with scarcely any organs, and differs from the genera already mentioned in remaining within its egg membrane, and not assuming their strange shapes. From the cylindrical sac-like non-segmented larva resembling the second larva of Platygaster it passes directly into the pupa state.

A fourth form, Teleas, is an egg parasite of Gerris, and in America one species oviposits in the eggs of Œcanthus.

The spindle-shaped larva in its first stage roughly resembles a trochosphere of a worm rather than the larva of an insect so high in the scale as a Hymenopter. It is active, but after moulting the second larva is oval, still without segments. Dr. Ayers gives a profusion of details and figures of the first and second stages of our Teleas, the second strongly resembling the Cyclops stage of Ganin. He describes three stages, and though he did not complete the life history of the insect he thinks it changes to an ovoid flattened form which succeeds the Cyclops stage in other Pteromalidæ, and that there are at least four ecdyses.

It is difficult to account for these strange larval forms, unless we suppose that the embryos, by their rich abundant food, have undergone a premature development, the growth of the body walls being greatly accelerated, the insects so to speak having been, under the stimulus of over-nutrition and their unusual environment, and perhaps also the high temperature of the egg, hurried into vermian existence on a plane scarcely higher than that of an active ciliated gastrula.

Further observations, difficult though they will be, are needed to enable us to account for the singular prematurity of the embryo of these parasites. That these stages are reversional and a direct inheritance from the vermian ancestors of these insects is not probable, but the forms are evidently the result of adaptation in response to a series of stimuli whose nature is in part appreciable but in part unknown.

It may be noted, however, that the appearance of a primitive band in the second larval stage indicates the origin of these forms, as well as that of insects in general, from a Peripatus-like, and again from an earlier leach-like Annelid ancestor. Hence the first larval or Cyclops stage is due to a precocious development caused by the unusual environment, and is simply adaptational, and not of phylogenetic significance.

V. ON THE INHERITANCE OF ACQUIRED CHARACTERS IN LEPIDOPTERA.

Perhaps in no other group of animals may we study the subject of the inheritance of acquired characters with more success than in the Lepidoptera. In these insects the four stages of existence, the egg, larva, pupa, and imago, are definite and fixed, and during each of the last three the organism is, so to speak, a different creature, with distinct and separate shape and structure external and internal, and during each stage leads a different life. Family, generic, and specific characters are inherited at each of these stages, and at each there is a combination of congenital and acquired characteristics, some of both classes of which, i. e. the least marked, are difficult to separate from one another. The following is an attempt at a rough grouping of such features at the last three stages.

We omit the egg stage, for though they more or less vary in shape and ornamentation, this is perhaps due more to difference in the structure of the lining of the oviduct of the female than to the action of external circumstances on the egg after it has been laid. Yet this should be said with some reservation, because we are not aware that any one has discussed the probable mode of origin of the specific differences in the shape and color of the eggs of birds, or the shape and markings of the eggs of insects; though undoubtedly the agency of external causes together with natural selection has something to do with the variation.*

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* It has seemed to us that the relation of specific and generic characteristics in the eggs of insects is a most difficult problem. Yet it should be observed that, while the differences in ornamentation and shape are primarily due to the impression on the shell received from the lining of the oviduct, yet the wonderful diversity we see in the eggs of insects is often readily seen to be correlated with the external conditions in which they exist, after having been deposited by the parent. As regards the eggs of birds, the thick solid shell and conico-

In the larval histories already published we have endeavored, where they have been observed with sufficient completeness, to discriminate between the congenital and the acquired characters.

1. *Larval State.* — A. In this state we have the inheritance of congenital characteristics.

B. Inheritance of what were originally acquired characters, the results of attacks of enemies. Examples are the tubercles armed with spines and sometimes with a singular kind of easily detached spines which are hence called caltrops (*Empretia*, etc.), stripes, spots: all apparently inherited at different periods of larval life; the least important specific and varietal characters probably having been originally acquired during the life of an individual.

2. *Pupal State.* — A. Cocoon: the absence or presence of a cocoon was doubtless originally due to differing external conditions: while the dense, perfect cocoon is characteristic of the spinning moths (*Attacidæ, Lasiocampidæ*, etc.); the Ceratocampidæ make none at all, but, like the Sphinges, the larvæ simply bury themselves in the earth before pupation. In the Arctiidæ and the Liparidæ the cocoon is chiefly composed of the barbed larval hairs, with a little silk to fasten them more firmly together: in the Geometridæ certain larvæ spin a loose thin web. In such cases the spinning of a cocoon is intimately associated with a change of larval habits, and is with little doubt an acquired habit, originally formed by a single individual.

B. The shape of the pupa is often dependent on the presence or absence of a cocoon. In the Notodontidæ the cremaster is often absent in genera (Gluphisia, which spins a very slight cocoon, and Lophodonta which spins no cocoon) which do not spin a cocoon,

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oval shape of the murre's eggs seem due to the unprotected manner in which they are left on rocks and shelves from which they are liable to fall. Here might be cited the suggestive essay of Prof. John Ryder, "The Mechanical Genesis of the Form of the Fowl's Egg," (Amer. Phil. Soc. Philadelphia, 1893, XXXI. 203–209.) in which he attempts to show that "the configuration of the outline of the hen's egg is determined by mechanical means, while the egg membranes and shell are in process of formation within the oviduct." We may contrast with the murre's egg that of the robin, in which the shell is thin and uniform in color, since it is protected from harm by being contained in a nest; so also the color of murres' eggs may be due to the action of protective mimicry, the spots assimilating them to lichen-grown or variously tinted rocks, by which they escape the observation of their natural enemies, the fox, the mink, and other egg-devouring animals. So the eggs of Chrysopa, of lice, of many bugs, etc., are in shape and mode of attachment beautifully adapted to prevent them from being seen by egg-destroying animals.

and are closely allied to those which do. In Cerura there is no spine on the rudimentary cremaster, because the pupa lies in a very dense cocoon. The cremaster affords excellent generic and specific characters. In the subterranean pupa of Datana it is present, and is of use in aiding the pupa to reach the surface of the ground. It is very large and acute in the subterranean pupæ of Ceratocampidæ and Sphinges. It is evident that in the presence or absence of a cremaster, and in its shape, and in the number of hooks and their shape, we have a set of very plastic characters, whose variability and plasticity are due to the varying habits of the pupa, whether living above or under ground, whether protected by a very thin loose netlike cocoon, or by a solid double one like that of Cerura or of the silk-worms. Also whether the thread is continuous and can be readily reeled, as in *Bombyx mori*, or whether the thread is often interrupted at the anterior end, as in *Platysamia cecropia*, is a feature which was probably the result of a slight change of circumstances, and may have been inaugurated as the result of variation in a single individual, during a single lifetime, becoming eventually fixed by homochronic inheritance.

III. *Imago Stage.* — It is easier to select what may have been acquired characters in caterpillars than in butterflies and moths, and yet the last have a complicated series of what may originally have been acquired characters. It should be borne in mind that, while caterpillars live for weeks and even months, are subject to frequent moults, are active and dependent on a proper supply of their food, usually this or that plant, butterflies and moths perish directly after mating, taking little or no food. Of course, acquired characters are most marked in the parts which are most used, as the maxillæ, wings, and external genital armature.

The absence of maxillæ, or their very rudimentary condition, in Bombycine moths, is with little doubt a recently acquired character. The very arbitrary distribution in Lepidoptera of scent-organs (androconia, etc.) is apparently a character recently acquired. The wonderful variations in the markings of the wings, due to a variety of slight causes, may often arise during an individual's lifetime and become a matter of inheritance, the result of sudden changes in temperature, moistness or dryness, and changes in food of the larva. By subjecting individual pupæ to prolonged cold or heat, varieties, and a greater or less number of broods, may be produced artificially, and this may illustrate how seasonal varieties have arisen in nature.

Many species are only separated by differences in the male genital armature. These, as is well known, are subject to great individual variation, and why should not the characters peculiar to a distinct variety, or even species, arise during the lifetime of two individuals when mated? Many individuals die without being mated; an unusually vigorous polygamous butterfly may have some new congenital extra development of hooks and processes, and by frequent use develop the muscles controlling these to the extent of providing an acquired character, which may be, if useful, inherited in the next and succeeding generations.

But an especially interesting and fruitful field of investigation would be a study of wingless Lepidoptera, such as the canker-worm, the autumn moths allied to it, the tussock moths (Orgyia), and especially the sac-bearers or Psychidæ.

The loss of wings in these cases seems originally to have been due to disuse in certain individuals more sluggish than others, and with little doubt has been the result of inheritance of what were originally acquired characters. It is easy to imagine how this has been induced by a study of a series of forms beginning with certain European genera in which the wings of the female are very small, and passing to those in which they become simple pads, as in the Orgyia, and ending with those, such as Anisopteryx, in which their reduction is still further carried out. And then examples like those should be compared with certain of the Ephemeræ, whose hind wings are so much reduced; with Pezzotettix and other Orthoptera with aborted wings, and certain Hemiptera in which the wings are aborted, ending with the great order of Diptera, comprising a vast number of species in which the hind wings have not only undergone a great reduction, but have been transformed through change of function into balancers, with their extraordinary sense-organs. It is not difficult to see that the disuse of wings may have begun in the life of a single individual, which, losing its wings, having perhaps inherited a tendency to this lesion through corpulency and other bodily changes, became inactive, averse to flight, and finally transmitted the peculiarity or the tendency to such peculiarity to its offspring.*

In a paper in the Proceedings of the Boston Society of Natural History (XXIV. 482) on the life history of *Drepana arcuata*, I have described the different stages of this moth, and at the end recapitulated the congenital characters, and finally given a synopsis of the chief steps in the evolution of the adaptational characters which appear after the first exuviation. It seems very probable that these later features were the result of the action of external stimuli, both physical and biological, and that they were acquired not only during the lifetime of the larva, but at certain distinct stages or periods during the growth of the creature. The changes are both colorational and structural. and during the different stages the larva was adapted for different surroundings, and thus at each important stage was virtually for the time being a distinct animal.

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* L. Knatz (Archiv für Naturgeschichte, LVII. 49-74, 1 pl., 1861) mentions 183 instances of reduced wings, and states that the reduction in wings is accompanied by an enlarged abdomen and an increase in the size of the ovaries, with greater fertility. Journ. Royal Microscopical Society for 1891, p. 462.

During the pupa stage special and unusual structural adaptations arose; the cremaster being unusually developed, and also a pair of cephalic hooks, serving to entangle the head in the web of the cocoon, so that the pupa cannot be thrown out of the curled leaf which remains in the first brood on the tree. These I regard as characters acquired by the insect after birth, and in response to the exigencies of life at different stages. The reader is also referred to the conclusions given in that paper.

Acquired Characters in the Notodontidæ. — In the systematic portion of my work on this group I have given a number of life histories of the family from papers recently published, and with more or less detail pointed out the later adaptational, as distinguished from the congenital characters. I have called attention, in late articles, to the varying shape of the tubercles and setæ in the larvæ of the Bombyces and other of the higher Lepidoptera, and to their probable mode of origin, and why they appear on certain segments in preference to others. The attention of the reader is called to the summary or recapitulation of changes especially in the life history of *Datana integerrima*, *Apatelodes torrefacta*, *Symmerista albifrons*, *Macrurocampa marthesia*, and several species of Cerura, while there is a summary of the steps in the assumption of the adaptive characters at the different larval stages of Schizura. The steps in the evolution of what may be regarded as acquired characters in Schizura. and in *Dasylophia anguina*, Hyparpax, Heterocampa, etc., are readily seen by an examination of the plates in the monograph referred to.

The Notodontians are remarkable in general for the humps, tubercles, and spines of their larvæ, some of which are congenital, while others appear at different stages after birth. Still some larvæ of this group are entirely without them, and remain so throughout their larval life. And this is an argument that the various processes of the cuticle or outgrowths of the entire integument are characters originally acquired during the post-embryonic life of the young insect.

Take, for example, the larval *Nadata gibbosa ;* this, like the caterpillar of Gluphisia and of Lophodonta is a smooth-bodied larva, ornamented with lines, but entirely unarmed. The life history of *N. gibbosa* shows that it is born with a smooth body, without any rudiments of tubercles or enlarged bristles, while no traces of the yellowish subdorsal lines appear until at the end of the second stage. This form is therefore a primitive one, and this fact would seem to demonstrate that the humps, tubercles, and spines, so frequently observed in the group, arose within recent geological times, and were acquired during the postembryonic stages of the larvæ of different genera, in response to various changes in the surroundings of different species, these finally becoming fixed and regularly transmitted along various lines of development, definite when the changes in the environment are definite, and resulting in a series of forms constituting the present genera of the family.

One of the most notable cases in the family is that of the loss at about the middle of the larval life of the remarkable antlers of *Heterocampa biundata.* During the three earliest stages the larva bears on the prothoracic segment a pair of enormous antlers, each with four tines. At the second moult these are discarded, and in the last two stages are represented by a pair of conical, rounded, polished, piliferous knobs. The rest of the partly grown body of the larva is smooth. After casting its horns the larva assumes a new set of colorational markings, so that in its last two stages it is a totally different creature in appearance from the earlier stages.

I have also observed the wonderful changes undergone by the caterpillar of *Heterocampa guttivitta,* representing five stages, nearly every one of which presents notable differences. In the first, directly after hatching, the reddish larva has not only a pair of enormous antlers with four tines on the first thoracic segment, but a pair of long antler-like spines on abdominal segments 1 to 6, and also 8 and 9; those on segments 1 and 8 being about three times as large as the others. It is certainly one of the most singular larvæ of the family.

Now this bizarre armature is entirely discarded at the first moult, excepting that the prothoracic antlers are represented by a pair of knob-like tubercles, the other segments, however, showing no trace of the former existence of spines. Also, while the body was not striped in Stage I., it is now paler red with a more brownish tint, and is marked with four yellowish stripes. At the end of this stage the lines become effaced, and the body grows more yellowish on the sides. In the third stage the tubercles still persist, but the markings differ very much, as reddish dorsal patches appear in the middle and near the end of the body, and there are anticipations of the markings of the fully grown caterpillar. In the present stage the insect closely resembles the mature larva, having bright crimson markings on the thoracic segments, and on the third and fourth and on the fifth and sixth abdominal segments, these bright spots becoming somewhat less decided and conspicuous in the final stage.

Now it seems natural to suppose that the disappearance of the armature of this insect with the first moult was due to the lack of need for it by the caterpillar, which gradually became adapted to a life on the under side of an oak leaf, where it assumed a simple spindle-shaped body, extended when at rest along the midrib, in which position we have found such caterpillars, its body glaucous green, and so marked with yellowish lines and reddish spots, as well as with dashes and lines, as to be wonderfully assimilated to the greenish, reddish, and whitish hues and shades of the leaf under which it was sheltered.

It also seems reasonable to suppose that these adaptational colorational features were acquired by the ancestors of the present forms during the different stages succeeding the first ecdysis. And thus we are warranted in assuming that this and multitudes of other cases of adaptation to the change in habits and modes of life, and special situations, were acquired originally at different periods after birth during an earlier geological period than this, when the ancestors were fewer in number and more plastic than now. Otherwise, how can we have had the differentiation of a few ancestral forms into the present series of genera, subfamilies, and families, represented by such a great number of species?

Indeed, it seems difficult to account for the evolution of the vast hordes of existing species of insects unless we assume that there was going on throughout the entire process the rise and perfecting of postnatal acquired characters, such characters becoming fixed by heredity, and reappearing with unerring certainty at different stages in the life of the individual; while in some animals whose postnatal metamorphosis through some environmental change became suppressed, we have the more salient stages epitomized during the life of the embryo.*

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* For many additional facts in the ontogeny of the Bombycine moths bearing on this subject the reader may be referred to my papers in the Proceedings of the Boston Society of Natural History, XXIV. 510–560, 1890; Journal of the

In his Chapter XIII. of "The Germ Plasm," Weismann gives an interesting example of the inheritance of climatic variation in butterflies. After an account of his recent experiments on *Polyommatus Phlœas*, he states: "Both experiments, however, prove the correctness of the old assumption of lepidopterists that the action of heat on a single generation is capable of giving the German form of a blackish tint; and since, moreover, it is clear that the development of a single generation at a lower temperature can render the color of the Neapolitan butterfly less black, it appears that the two varieties may have originated owing to a gradual cumulative influence of the climate, the slight effects of one summer or winter having been transmitted and added to from generation to generation. *This would then seem to be an instance of the transmission of acquired characters.*" He then adds, that he does not believe that this is the correct interpretation of the facts; on the contrary he insists: "The theory of determinants will I believe supply a very simple explanation of this apparently complicated case, which I consider of great value, because it confirms this theory. Instead of supporting the doctrine of the transmission of somatogenic characters, this example shows how *such a process may apparently be brought about*, and on what it depends. A somatogenic character is not in this case inherited, but the modifying influence — the temperature — *affects the primary constituents of the wings in each individual*, — i. e. a part of the soma — *as well as the germ plasm contained in the germ cells of the animal.* It modifies the *same* determinants in the rudiments of the wings of the young chrysalis as in the germ cells, namely, those of the wing scales," etc.

We certainly prefer the more simple explanation first given, but only to be rejected, by Weismann, since it appears to be really based on observed facts, and to be a natural and logical induction from such facts, and is thus a more scientific explanation. The same process of reasoning will apply to the inheritance of acquired characters in the ontogeny of the Lepidoptera and that of other groups, such as we have endeavored to set forth in this essay.

It is, moreover, a simple and natural inference, such as in the case of the butterflies experimented on by Weismann, and would be the

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New York Entomological Society, I. 22–28, 57–76; Proceedings Amer. Phil. Soc. Philad., February, 1893, pp. 83–108, March, 1893, pp. 139–192; Proc. Amer. Acad. Arts and Sciences, Boston, 1893, XXVIII. 55–92; Annals New York Acad. Sci., May, 1893, VIII. 41–92. Also Monograph of the Bombycine Moths of North America, Part I., in course of publication in the Memoirs of the National Academy of Sciences, Vol. VII.

first explanation which would suggest itself to any observer. On the other hand, the extremely complicated speculative and *a priori* second explanation of Weismann, based as it is on pure assumptions, does not carry conviction, and thus is not an efficient working hypothesis to explain inheritance at corresponding periods of life.

It is noticeable that in his writings Weismann does not touch upon homochronous heredity, though his earlier work, "Studies in the Theory of Descent" (1876), which is largely based on Lamarckian views, afterward abandoned by the author, is a storehouse of the most suggestive facts.

In seeking to explain the causes of a metamorphosis in animals, one is compelled to go back to the primary factors of organic evolution, such as the change of environment, whether the factors be cosmical (gravity), physical changes in temperature, effects of increased or diminished light and shade, under or over nutrition, and the changes resulting from the presence or absence of enemies, or of isolation. The action of these factors, whether direct or indirect, is obvious, when we try to explain the origin or causes of the more marked metamorphoses of animals. Then come in the other Lamarckian factors of use and disuse, new needs resulting in new modes of life, habits, or functions, which bring about the origination, development, and perfection of new organs, as in new species and genera, etc., or which in metamorphic forms may result in a greater increase in the number of, and an exaggeration of the features characterizing the stages of larval life.

VI. The Adequacy of Neolamarckism.

It is not to be denied that in many instances all through the ceaseless operation of these fundamental factors there is going on a process of sifting or of selection of forms best adapted to their surroundings, and best fitted to survive, but this factor, though important, is quite subordinate to the initial causes of variation, and of metamorphic changes.

Neolamarckism,* as we understand this doctrine, has for its founda-

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* In 1885, in the Introduction to the "Standard Natural History," we proposed the term Neolamarckianism, or Lamarckism in its modern form, to designate the series of factors of organic evolution, and we take the liberty to quote the passage in which the word first occurs. We may add that the briefer form, Neolamarckism, is the more preferable.

"In the United States a number of naturalists have advocated what may be called Neo-Lamarckian views of evolution, especially the conception that in tion a combination of the factors suggested by the Buffon and Geoffroy St. Hilaire school, which insisted on the direct action of the *milieu*, and of Lamarck, who relied on the indirect action of the environment, adding the important factors of need and of change of habits resulting either in the atrophy or in the development of organs by disuse or use, with the addition of the hereditary transmission of characters acquired in the lifetime of the individual.

Lamarck's views, owing to the early date of his work, which was published in 1809, before the foundation of the sciences of embryology, cytology, palæontology, zoögeography, and in short all that distinguishes modern biology, were necessarily somewhat crude, though the fundamental factors he suggested are those still invoked by all thinkers of Lamarckian tendencies.

Neolamarckism gathers up and makes use of the factors both of the St. Hilaire and Lamarckian schools, as containing the more fundamental causes of variation, and adds those of geographical isolation or segregation (Wagner and Gulick), the effects of gravity, the effects of currents of air and of water, of fixed or sedentary as opposed to active modes of life, the results of strains and impacts (Ryder, Cope, and Osborn), the principle of change of function as inducing

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some cases rapid evolution may occur. The present writer, contrary to pure Darwinians, believes that many species, but more especially types of genera and families, have been produced by changes in the environment acting often with more or less rapidity on the organism, resulting at times in a new genus, or even a family type. Natural selection, acting through thousands, and sometimes millions, of generations of animals and plants, often operates too slowly; there are gaps which have been, so to speak, intentionally left by Nature. Moreover, natural selection was, as used by some writers, more an idea than a *vera causa*. Natural selection also begins with the assumption of a tendency to variation, and presupposes a world already tenanted by vast numbers of animals, among which a struggle for existence was going on, and the few were victorious over the many. But the entire inadequacy of Darwinism to account for the primitive origin of life forms, for the original diversity in the different branches of the tree of life forms, the interdependence of the creation of ancient faunas and floras on geological revolutions, and consequent sudden changes in the environment of organisms, has convinced us that Darwinism is but one of a number of factors of a true evolution theory; that it comes in play only as the last term of a series of evolutionary agencies or causes; and that it rather accounts, as first suggested by the Duke of Argyll, for the *preservation* of forms than for their origination. We may, in fact, compare Darwinism to the apex of a pyramid, the larger mass of the pyramid representing the complex of theories necessary to account for the world of life as it has been and now is. In other words, we believe in a modified and greatly extended Lamarckianism, or what may be called Neo-Lamarckianism."

the formation of new structures (Dohrn), the effects of parasitism, commensalism, and of symbiosis, in short the biological environment; together with geological extinction, natural and sexual selection, and hybridity.

It is to be observed that the Neolamarckian in relying mainly on these factors does not overlook the value of natural selection as a guiding principle, and which began to act as soon as the world became stocked with the initial forms of life, but he simply seeks to assign this principle to its proper position in the hierarchy of factors.

Natural Selection, as the writer from the first has insisted, is not a *vera causa*, an initial or impelling cause in the origination of new species and genera. It does not start the ball in motion; it only so to speak guides its motions down this or that incline. It is the expression, like that of "the survival of the fittest" of Herbert Spencer, of the results of the combined operation of the more fundamental factors. In certain cases we cannot see any room for its action; in some others we cannot at present explain the origin of species in any other way. Its action increased in proportion as the world became more and more crowded with diverse forms, and when the struggle for existence had become more unceasing and intense. It certainly cannot account for the origination of the different branches, classes, or orders of organized beings. It in the main simply corresponds to artificial selection; in the latter case, man selects forms already produced by domestication, the latter affording sports and varieties due to change in the surroundings, that is, of soil, climate, food, and other physical features, as well as education.

In the case also of heredity, which began to operate as soon as the earliest life forms appeared, we have at the outset to invoke the principle of the heredity of acquired characters during the lifetime of the lowest organisms.

Finally, it is noticeable that when one is overmastered by the dogma of natural selection he is apt, perhaps unconsciously, to give up all effort to work out the factors of evolution, or to seek to work out this or that cause of variation. Trusting too implicitly to the supposed *vera causa*, one may close his eyes to the effects of change of environment or to the necessity of constant attempts to discover the real cause of this or that variation, the reduction or increase in size of this or that organ; or become insensible to the value of experiments. Were the dogma of natural selection to become universally accepted, further progress would cease, and biology would tend to relapse into a stage of atrophy and degeneration. On the other hand a revival of

Lamarckism in its modern form, and a critical and doubting attitude towards natural selection as an efficient cause, will keep alive discussion and investigation, and especially, if resort be had to experimentation, will carry up to a higher plane the status of philosophical biology.

XVI.

ON THE GROUP OF AUTOMORPHIC LINEAR TRANSFORMATIONS OF A BILINEAR FORM.

BY HENRY TABER.

Presented February 14, 1894.

§ 1. *Alternate Bilinear Form.*

1. In the *Philosophical Transactions* for 1858, Cayley gave the following identity between two matrices, viz.: —

$$(\Omega - \Upsilon)\ (\Omega + \Upsilon)^{-1}\,\Omega\,(\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon) = \Omega.$$

From this identity Cayley derives the general solution of the matrical equation $\breve{\phi}\,\Omega\,\phi = \Omega$, in which Ω is a skew symmetric matrix and $\breve{\phi}$ denotes the transverse of ϕ. Thus for ϕ Cayley gives the expression

$$(\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon),$$

in which Υ is an arbitrary skew symmetric matrix, but such that

$$|\,\Omega - \Upsilon\,| \neq 0.$$

From this expression may be derived

$$\breve{\phi} = (\Omega - \Upsilon)\ (\Omega + \Upsilon)^{-1};$$

therefore, substituting, the above equation is satisfied identically.

As shown by Cayley, the solution of this equation is equivalent to the determination of the automorphic linear transformation of the alternate bilinear form

$$(\Omega)\overset{\wedge}{}(x_1, x_2, \ldots)\overset{\wedge}{}(y_1, y_2, \ldots),$$

the x's and y's being cogrediant.

Cayley's expression gives every solution with non-vanishing determinant of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$, except those of which -1 is a latent root (root of the characteristic equation). If $|\,\Omega\,| \neq 0$, and if ϕ satisfies the above equation, $|\phi| \neq 0$. In what follows it will be assumed that the determinant of the skew symmetric matrix Ω is not zero.

Since the product of any two matrices satisfying the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ is again a solution of this equation, the matrices satisfying this equation form a group. This group can be generated by the solutions of the equation given by Cayley's expression.* For every solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ is given by the product of four of Cayley's expressions. See (2) and (10).

The group of solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ can be generated by the matrices of the group which differ infinitesimally from the matrix unity; for, see (2) and (5), every solution given by Cayley's expression can be formed by the product into itself an infinite number of times of a solution (given also by Cayley's expression) which differs infinitesimally from the matrix unity.

The group of matrices satisfying the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ is identical with the group of linear substitutions which automorphically transform the alternate bilinear form

$$(\Omega)\overset{\wedge}{}(x_1, x_2, \ldots)\overset{\wedge}{}(y_1, y_2, \ldots),$$

in which the x's and y's are cogrediant. Therefore, this group can be generated by the infinitesimal transformations of the group, namely, those differing infinitesimally from the identical substitution.

2. The proof of these theorems relating to the group of solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ may be made to depend upon the proof in the special case in which the skew symmetric matrix Ω is also orthogonal (i. e. if $\Omega^2 = -1$).

Thus, let

$$\breve{\phi}\,\Omega\,\phi = \Omega.$$

If $\Omega^2 \neq -1$, let ω denote any fourth root of $-\Omega^2$ expressible in powers of Ω^2; then ω is symmetric and is commutative with Ω. Therefore,

$$\omega^{-1}\,\breve{\phi}\,\omega\,\frac{\Omega}{\omega^2}\,\omega\,\phi\,\omega^{-1} = \frac{\Omega}{\omega^2}.$$

If $\psi = \omega\,\phi\,\omega^{-1}$, $\Omega' = \dfrac{\Omega}{\omega^2}$, this becomes

$$\breve{\psi}\,\Omega'\,\psi = \Omega',$$

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* This has been proved otherwise by Frobenius Crelle, 1878, who shows that every solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ which is not given by Cayley's expression is given by the limit of this expression when the symmetric matrix Υ becomes infinite.

in which $\breve{\Omega}' = -\Omega'$, and $\Omega'^2 = -1$. If ψ is given by the product of four such expressions as

$$(\Omega' - \Upsilon')^{-1} (\Omega' + \Upsilon'),$$

in which Υ' is symmetric; then since this expression is equal to

$$\begin{aligned} &= \left(\frac{\Omega}{\omega^2} - \Upsilon'\right)^{-1} \left(\frac{\Omega}{\omega^2} + \Upsilon'\right) \\ &= \omega\, (\Omega - \omega\, \Upsilon' \omega)^{-1}\, \omega \cdot \omega^{-1} (\Omega + \omega\, \Upsilon' \omega)\, \omega^{-1} \\ &= \omega \cdot (\Omega - \Upsilon)^{-1} (\Omega + \Upsilon) \cdot \omega^{-1}, \end{aligned}$$

in which $\Upsilon = \omega\, \Upsilon' \omega$ is symmetric; therefore $\phi = \omega^{-1} \psi\, \omega$ is the product of four of Cayley's expressions.

Further, if ϕ is a solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$, given by Cayley's expression, then $\psi = \omega\, \phi\, \omega^{-1}$ is a solution of the equation $\breve{\psi}\, \Omega' \psi = \Omega'$ given by Cayley's expression. Therefore, if ψ is equal to the product into itself an infinite number of times of a solution of the equation $\breve{\psi}\, \Omega' \psi = \Omega'$, differing infinitesimally from the matrix unity, ϕ is equal to the product into itself an infinite number of times of a solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$, differing infinitesimally from the matrix unity.*

3. Let now ϕ be any solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$. in which $\breve{\Omega} = -\Omega$, and $\Omega^2 = -1$ (and therefore $\breve{\Omega}\, \Omega = 1$). The complete determination of ϕ may be obtained by the consideration of the identity

$$e^{-\Omega\, \theta}\, \Omega\, e^{\theta\, \Omega} = \Omega,$$

in which $e^{\theta\, \Omega}$ denotes the exponential series $\sum_{0}^{\infty}{}_r \frac{(\theta\, \Omega)^r}{r\,!}$, convergent for any matrix. Thus, let $-\Omega\, \theta$ be a polynomial in $\breve{\phi}$, satisfying the equation $\breve{\phi} = e^{-\Omega\, \theta}$. We then have $\phi = e^{\breve{\theta}\, \Omega}$; but the identity gives $\phi = e^{\theta\, \Omega}$. Since $-\Omega\, \theta$ is a polynomial in $\breve{\phi}$, $\breve{\theta}\, \Omega$ is a polynomial in ϕ; and since $\phi^{-1} = \Omega^{-1} \breve{\phi}\, \Omega$, $\theta\, \Omega = \Omega^{-1} (\Omega\, \theta)\, \Omega$ is also a polynomial in ϕ. Consequently, $\breve{\theta}\, \Omega$ and $\theta\, \Omega$ are commutative. Therefore,

$$e^{(\theta - \breve{\theta})\, \Omega} = e^{\theta\, \Omega}\, e^{-\breve{\theta}\, \Omega} = e^{\theta\, \Omega} \,.\, (e^{\breve{\theta}\, \Omega})^{-1} = \phi\, \phi^{-1} = 1.$$

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* Moreover, if ϕ is a solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$, given by Cayley's expression, it may be given the exponential representation $e^{\theta\, \Omega}$ in which θ is symmetric. For any symmetric matrix θ, $e^{\theta\, \Omega}$ is a solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$. Therefore, for any integer n, $e^{\frac{1}{n}\theta\, \Omega}$ is a solution. But $\left(e^{\frac{1}{n}\theta}\right)^n = e^{\theta} = \phi$. Whence the theorem. See note to (5).

4. Conversely, if θ is any matrix for which $\breve{\theta}\,\Omega\,\theta = \theta\,\Omega\,\breve{\theta}$ and $e^{(\theta-\breve{\theta})\Omega} = 1$, then $\phi = e^{\theta\Omega}$ is a solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$. In particular, if θ is symmetric, $e^{\theta\Omega}$ is a solution of this equation, and so also is $e^{\frac{1}{n}\theta\Omega}$, in which n is any positive integer. But $(e^{\frac{1}{n}\theta\Omega})^n = e^{\theta\Omega}$. Therefore, every expression $e^{\theta\Omega}$ in which θ is symmetric is a solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$, and can be generated by the product into itself an infinite number of times of a matrix which is a solution of this equation, and differs only infinitesimally from the matrix unity.

Let $\phi = e^{\theta\Omega}$ in which θ is symmetric. If the positive integer n is sufficiently great, no odd multiple of $\pi\sqrt{-1}$ is a latent root of $\frac{1}{n}\theta\,\Omega$; and therefore -1 is not a latent root of $e^{\frac{1}{n}\theta\Omega}$. But $\phi = (e^{\frac{1}{n}\theta\Omega})^n$. Therefore, ϕ is the nth power of a matrix given by Cayley's expression.

5. Every solution of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$, given by Cayley's expression, can be put in the form $e^{\theta\Omega}$ in which θ is symmetric. Thus, let

$$\begin{aligned}\phi &= (\Omega - \Upsilon)^{-1}\,(\Omega + \Upsilon)\\ &= \Omega^{-1}\,.\,(1 - \Upsilon\Omega^{-1})^{-1}\,(1 + \Upsilon\Omega^{-1})\,.\,\Omega,\end{aligned}$$

in which Υ is symmetric. If now $\vartheta' = f(-\Upsilon\Omega^{-1})$ is a polynomial in $-\Upsilon\Omega^{-1}$, satisfying the equation

$$e^{\vartheta'} = 1 - \Upsilon\Omega^{-1},$$

then $\vartheta'' = f(\Upsilon\Omega^{-1})$ will satisfy the equation

$$e^{\vartheta''} = 1 + \Upsilon\Omega^{-1}.\text{*}$$

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* Since $|\phi| \neq 0$, and therefore $|1 - \Upsilon\Omega^{-1}| \neq 0$, $|1 + \Upsilon\Omega^{-1}| \neq 0$, such polynomials in $-\Upsilon\Omega^{-1}$ and $\Upsilon\Omega^{-1}$ can always be formed; and if $e^{f(-\Upsilon\Omega^{-1})} = 1 - \Upsilon\Omega^{-1}$, equating the transverse of either member, we have

$$e^{f(\Omega^{-1}\Upsilon)} = 1 + \Omega^{-1}\Upsilon.$$

That is,

$$\begin{aligned}\Omega^{-1}e^{f(\Upsilon\Omega^{-1})}\,\Omega &= e^{\Omega^{-1}f(\Upsilon\Omega^{-1})\,\Omega}\\ &= e^{f(\Omega^{-1}\,.\,\Upsilon\Omega^{-1}\,.\,\Omega)}\\ &= e^{f(\Omega^{-1}\Upsilon)}\\ &= 1 + \Omega^{-1}\Upsilon\\ &= \Omega^{-1}(1 + \Upsilon\Omega^{-1})\,\Omega.\end{aligned}$$

Therefore,

$$e^{f(\Upsilon\Omega^{-1})} = 1 + \Upsilon\Omega^{-1}.$$

Since $\vartheta' \vartheta'' = \vartheta'' \vartheta'$, we have

$$\begin{aligned} \phi &= \Omega^{-1} (e^{\vartheta'})^{-1} e^{\vartheta''} \Omega \\ &= \Omega^{-1} e^{-\vartheta'} e^{\vartheta''} \Omega \\ &= \Omega^{-1} e^{-\vartheta' + \vartheta''} \Omega \\ &= e^{\Omega^{-1}(-\vartheta' + \vartheta'')\Omega}. \end{aligned}$$

But $-\vartheta' + \vartheta''$ is a polynomial in odd powers of $\Upsilon \Omega^{-1}$; and since $\Omega^{-1} (\Upsilon \Omega^{-1})^{2r+1}$ for any positive integer r is symmetric, $\Omega^{-1}(-\vartheta' + \vartheta'')\Omega$ is the product of a symmetric matrix into Ω.

Whence it follows that every solution of the equation $\breve{\phi} \Omega \phi = \Omega$ given by Cayley's expression is the product into itself an infinite number of times of a solution which differs only infinitesimally from the matrix unity.[*]

6. Assuming that $\theta \Omega$ is a polynomial in ϕ satisfying the equation $\breve{\phi} \Omega \phi = \Omega$, let $\bar{\phi} = e^{\frac{1}{2}(\theta + \breve{\theta})\Omega}$, and $\phi_0 = e^{\frac{1}{2}(\theta - \breve{\theta})\Omega}$. Then, by (3),

$$\phi = \bar{\phi} \phi_0 = \phi_0 \bar{\phi};$$

and, by (3) and (4),

$$\breve{\bar{\phi}} \Omega \bar{\phi} = \Omega, \quad \breve{\phi}_0 \Omega \phi_0 = \Omega, \quad \phi_0^2 = 1.$$

By (4), $\bar{\phi}$ is the product of matrices given by Cayley's expression. But the matrix θ may be so chosen that no integer multiple of $\pi \sqrt{-1}$ other than zero is a latent root of $\frac{1}{2}(\theta + \breve{\theta})\Omega$, in which case $\bar{\phi}$ is given by Cayley's expression.[†]

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[*] In the three preceding sections (3), (4), (5), the assumption $\Omega^2 = -1$ has not been employed in the demonstration. The theorems therein given, therefore, hold for any skew symmetric matrix whose determinant does not vanish.

[†] It is readily shown that $\bar{\phi}$ is given by the square of Cayley's expression. For if some integer multiple of $2\pi\sqrt{-1}$ other than zero is a latent root of $\theta \Omega$, a matrix $\theta' \Omega$ also a polynomial in ϕ can be found, of which no integer multiple of $2\pi\sqrt{-1}$ other than zero is a latent root, such that $\phi = e^{\theta \Omega} = e^{\theta' \Omega}$. But then no integer multiple of $2\pi\sqrt{-1}$ other than zero is a latent root of $\Omega \breve{\theta}'$ and therefore of $\breve{\theta}' \Omega$. Consequently, no integer multiple of $\frac{\pi\sqrt{-1}}{2}$ other than zero is a latent root either of $\frac{\theta' \Omega}{4}$ or of $\frac{\breve{\theta}' \Omega}{4}$. Whence it follows that -1 is not a latent root either of $e^{\frac{1}{4}\theta'\Omega}$ or $e^{\frac{1}{4}\breve{\theta}'\Omega}$; and since these matrices are commutative, -1 is not a latent root of their product. Therefore, $e^{\frac{1}{4}(\theta' + \breve{\theta}')\Omega}$ is given by Cayley's expression, and $\bar{\phi} = e^{\frac{1}{2}(\theta' + \breve{\theta}')\Omega}$ by the square of Cayley's expression.

7. If ϕ is symmetric, $\theta\,\Omega + \Omega\,\breve{\theta} = 0$, and therefore $\breve{\phi}_0 = \phi_0$. Let

$$\Theta = \Omega\,\phi_0,$$

then $\breve{\Theta} = -\Theta$, $\breve{\Theta}\,\Omega\,\Theta = \Omega$; moreover, $\Theta^2 = -1$. Consequently, Θ is given by Cayley's expression; and therefore

$$\phi = \phi_0\,\bar{\phi} = \Omega^{-1}\,\Theta\,\bar{\phi}$$

is the product of three of Cayley's expressions.

8. If ϕ is orthogonal, it is commutative with Ω; therefore θ and $\breve{\theta}$ are commutative with Ω. Consequently,

$$\breve{\bar{\phi}} = e^{-\frac{1}{2}\Omega(\theta + \breve{\theta})} = e^{-\frac{1}{2}(\theta + \breve{\theta})\Omega} = \bar{\phi}^{-1}$$

$$\breve{\phi}_0 = e^{\frac{1}{2}\Omega(\theta - \breve{\theta})} = e^{\frac{1}{2}(\theta - \breve{\theta})\Omega} = \phi_0.$$

From the last equation follows

$$\Omega\,\phi_0 = \phi_0\,\Omega.$$

Let now

$$\Theta = \Omega\,\phi_0;$$

then $\breve{\Theta} = -\Theta$, $\breve{\Theta}\Omega\Theta = \Omega$, and $\Theta^2 = -1$. Consequently, Θ is given by Cayley's expression.

We have $\phi = \Omega^{-1}\,\Theta\,\bar{\phi}$; therefore any orthogonal matrix satisfying the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ is the product of Ω^{-1} into two of Cayley's expressions. But $\Omega^{-1}\,\phi$ is orthogonal, and is also a solution of this equation, and consequently can be thus expressed. Whence it follows that ϕ is given by the product of two of Cayley's expressions.*

9. This theorem holds if $\Omega^2 \neq -1$. In this case, if $\breve{\phi}\,\Omega\,\phi = \Omega$ and ϕ is orthogonal, let ω be any fourth root of $-\Omega^2$ expressible in powers of Ω^2. Then

$$\omega^{-1}\,\breve{\phi}\,\omega\,\frac{\Omega}{\omega^2}\,\omega\,\phi\,\omega^{-1} = \Omega.$$

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* The two matrices given by Cayley's expression whose product is equal to ϕ can both be taken orthogonal. For in the equation $\phi = \Omega^{-1}\,\Theta\,\bar{\phi}$ the matrices Θ and $\bar{\phi}$ are orthogonal. Similarly, if $\Omega^{-1}\,\phi = \psi = \Omega^{-1}\,\Theta'\,\bar{\psi}$, the two matrices Θ' and $\bar{\psi}$ given by Cayley's expression are orthogonal. Therefore, $\phi = \Omega\,\psi$ is the product of two orthogonal Cayleyan solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$.

If the expression $(\Omega - \Upsilon)^{-1}(\Omega \div \Upsilon)$ is orthogonal $\Omega\,\Upsilon = \Upsilon\,\Omega$. Therefore, the orthogonal subgroup of solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ in which $\Omega^2 = -1$ is generated by the totality of such expressions for all symmetric matrices Υ commutative with Ω and such that $|\,\Omega - \Upsilon\,| \neq 0$.

But ϕ is commutative with Ω, and consequently with ω. Therefore,

$$\breve{\phi}\,\frac{\Omega}{\omega^2}\,\phi = \frac{\Omega}{\omega^2};$$

and by the last theorem we may put

$$\begin{aligned}\phi &= \left(\frac{\Omega}{\omega^2} - \Upsilon'_a\right)^{-1}\left(\frac{\Omega}{\omega^2} + \Upsilon'_a\right)\left(\frac{\Omega}{\omega^2} - \Upsilon'_\beta\right)^{-1}\left(\frac{\Omega}{\omega^2} + \Upsilon'_\beta\right)\\ &= \omega\,(\Omega - \omega\,\Upsilon'_a\,\omega)^{-1}(\Omega + \omega\,\Upsilon'_a\,\omega)\,(\Omega - \omega\,\Upsilon'_\beta\,\omega)^{-1}(\Omega + \omega\,\Upsilon'_\beta\,\omega)\,\omega^{-1}\\ &= \omega\,(\Omega - \Upsilon_a)^{-1}(\Omega + \Upsilon_a)\,(\Omega - \Upsilon_\beta)^{-1}(\Omega + \Upsilon_\beta)\,\omega^{-1},\end{aligned}$$

in which Υ'_a, Υ'_β, and therefore $\Upsilon_a = \omega\,\Upsilon'_a\,\omega$, $\Upsilon_\beta = \omega\,\Upsilon'_\beta\,\omega$, are symmetric. Whence it follows that

$$\phi = \omega^{-1}\,\phi\,\omega = (\Omega - \Upsilon_a)^{-1}(\Omega + \Upsilon_a)\,(\Omega - \Upsilon_\beta)^{-1}(\Omega + \Upsilon_\beta)$$

is the product of two of Cayley's expressions.*

10. If ϕ is neither symmetric nor orthogonal, let

$$\Theta = \Omega\,\phi_0;$$

whence it follows that $\breve{\Theta} = -\Theta$, and $\breve{\Theta}\,\Omega\,\Theta = \Omega$.

Let $\theta'\,\Omega$ be a polynomial in Θ satisfying the equation $\Theta = e^{\theta'\Omega}$; and let

$$\overline{\Theta} = e^{\frac{1}{2}(\theta' + \breve{\theta}')\Omega},\ \Theta_0 = e^{\frac{1}{2}(\theta' - \breve{\theta}')\Omega}.$$

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[*] It is not proved that the two factors of ϕ are orthogonal. But it can be readily proved that ϕ is equal to the product of three matrices given by Cayley's expression, each of which is orthogonal; and therefore the sub-group of orthogonal solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ can be generated by the Cayleyan solutions of this sub-group; or, what is the same thing, by the orthogonal matrices commutative with Ω and of which $+1$ is not a latent root.

For, if ϕ is orthogonal, we may put $\phi = \phi_0\,\overline{\phi}$, where $\overline{\phi}$ is an orthogonal matrix of which -1 is not a latent root and ϕ_0 is a symmetric orthogonal matrix, both ϕ_0 and $\overline{\phi}$ being polynomials in ϕ. (See these Proceedings, Vol. XXVIII. p. 219.) If now $\breve{\phi}\,\Omega\,\phi = \Omega$, then $\breve{\overline{\phi}}\,\Omega\,\overline{\phi} = \Omega$, and $\phi_0\,\Omega = \Omega\,\phi_0$. From the last equation follows

$$\phi_0\,\frac{\Omega}{\omega^2} = \frac{\Omega}{\omega^2}\,\phi_0.$$

Therefore, by (8)

$$\begin{aligned}\phi_0 &= \left(\frac{\Omega}{\omega^2}\right)^{-1}\left(\frac{\Omega}{\omega^2} - \Upsilon\right)^{-1}\left(\frac{\Omega}{\omega^2} + \Upsilon\right)\\ &= \omega\,(\Omega - \omega^2)^{-1}(\Omega + \omega^2)\,(\Omega - \omega\,\Upsilon\,\omega)^{-1}(\Omega + \omega\,\Upsilon\,\omega)\,\omega^{-1}.\end{aligned}$$

Therefore, $\phi_0 = \omega^{-1}\,\phi_0\,\omega$ is the product of two of Cayley's expressions. Moreover, the first factor, namely, $(\Omega - \omega^2)^{-1}(\Omega + \omega^2)$ is orthogonal; and, since ϕ_0 is orthogonal, the second factor of ϕ_0 is also orthogonal. Therefore, $\phi = \phi_0\,\phi$ is the product of three solutions of the equation $\breve{\phi}\,\Omega\,\phi = \Omega$ given by Cayley's expression, each of which is orthogonal.

Then

$$\breve{\bar{\Theta}}\, \Omega\, \bar{\Theta} = \Omega, \quad \breve{\Theta}_0\, \Omega\, \Theta_0 = \Omega, \quad \Theta_0{}^2 = 1\,;$$

and, if θ' is properly chosen, -1 is not a latent root of $\bar{\Theta}$, which is then given by Cayley's expression.

Since Θ is skew symmetric, $\theta'\, \Omega$, $\breve{\theta}'\, \Omega$, $\Omega\, \theta'$, $\Omega\, \breve{\theta}'$, are commutative. Therefore,

$$\breve{\Theta}_0\, \Theta_0 = \Theta_0\, \breve{\Theta}_0.$$

Whence follows

$$(\breve{\Theta}_0\, \Theta_0)^2 = \breve{\Theta}_0{}^2\, \Theta_0{}^2 = 1.$$

Let now

$$\Omega\, \Theta_0 = \Gamma\,;$$

then $\breve{\Gamma} = -\Gamma$, and $\breve{\Gamma}\, \Omega\, \Gamma = \Omega$. We also have

$$\breve{\Theta}_0\, \Theta_0 = -\Gamma^2\,;$$

and therefore

$$\Gamma^4 = 1.$$

A symmetric matrix ϖ of non-zero determinant can be found to satisfy the equation $\breve{\Gamma}\, \varpi\, \Gamma = \varpi$. And if $\varpi^{\frac{1}{2}}$ denotes any symmetric square root of ϖ, the last equation may be written

$$(\varpi^{\frac{1}{2}})^{-1}\breve{\Gamma}\, \varpi^{\frac{1}{2}} \,.\, \varpi^{\frac{1}{2}}\, \Gamma\, (\varpi^{\frac{1}{2}})^{-1} = 1\,;$$

which, if $\psi = \varpi^{\frac{1}{2}}\, \Gamma\, (\varpi^{\frac{1}{2}})^{-1}$, becomes

$$\breve{\psi}\, \psi = 1.$$

Therefore,

$$\Gamma = (\varpi^{\frac{1}{2}})^{-1}\, \psi\, \varpi^{\frac{1}{2}},$$

in which ψ is orthogonal. But, since $\breve{\Gamma}\, \Omega\, \Gamma = \Omega$, ψ is commutative with $(\varpi^{\frac{1}{2}})^{-1}\, \Omega\, (\varpi^{\frac{1}{2}})^{-1}$. Therefore, by (9) ψ is equal to the product of two expressions of the form

$$\begin{aligned}
&[(\varpi^{\frac{1}{2}})^{-1}\Omega\, (\varpi^{\frac{1}{2}})^{-1} - \Upsilon']^{-1}[(\varpi^{\frac{1}{2}})^{-1}\, \Omega\, (\varpi^{\frac{1}{2}})^{-1} + \Upsilon'] \\
&= \varpi^{\frac{1}{2}}\, (\Omega - \varpi^{\frac{1}{2}}\, \Upsilon'\, \varpi^{\frac{1}{2}})^{-1}\, \varpi^{\frac{1}{2}} \cdot (\varpi^{\frac{1}{2}})^{-1}\, (\Omega + \varpi^{\frac{1}{2}}\, \Upsilon'\, \varpi^{\frac{1}{2}})\, (\varpi^{\frac{1}{2}})^{-1} \\
&= \varpi^{\frac{1}{2}}\, (\Omega - \Upsilon)^{-1}\, (\Omega + \Upsilon)\, (\varpi^{\frac{1}{2}})^{-1},
\end{aligned}$$

in which Υ' and therefore $\Upsilon = \varpi^{\frac{1}{2}}\, \Upsilon\, \varpi^{\frac{1}{2}}$, is symmetric. Whence it follows that $\Gamma = (\varpi^{\frac{1}{2}})^{-1}\, \psi\, \varpi^{\frac{1}{2}}$ is the product of two of Cayley's expressions. Therefore,

$$\begin{aligned}
\phi = \phi_0\, \bar{\phi} = \Omega^{-1}\, \Theta\, \bar{\phi} &= \Omega^{-1}\, \Theta_0\, \bar{\Theta}\, \bar{\phi} \\
&= -\Gamma\, \bar{\Theta}\, \bar{\phi}
\end{aligned}$$

is equal to the negative of the product of four of Cayley's expressions. Since $-\phi$ is also a solution of the equation $\breve{\phi}\, \Omega\, \phi = \Omega$, it is also expressible thus. Whence it follows that ϕ is given by the product of four of Cayley's expressions.

11. If ϕ is real, θ may be so chosen that $\bar{\phi}$ and ϕ_0 are real; and then, if Ω is real, $\Theta = \Omega^{-1}\phi_0$ is real. But then, since Θ is real and skew symmetric, -1 is not a latent root of Θ, which is therefore given by Cayley's expression.

Whence it follows that any real matrix ϕ satisfying the equation $\check{\phi}\,\Omega\,\phi = \Omega$, in which Ω is real, is the product of Ω^{-1} into two of Cayley's expressions. But $\Omega^{-1}\phi$ is then also a real solution of this equation, and can therefore be thus expressed. Consequently, ϕ is equal to the product of two of Cayley's expressions.*

In each of the factors of ϕ given by Cayley's expression, the symmetric matrix may be taken real.

12. These theorems may be extended to the real solutions of the equation $\check{\phi}\,\Omega\,\phi = \Omega$, in which Ω is any real skew symmetric matrix whose determinant does not vanish. For if Ω is real, the latent roots of $-\Omega^2$ are all positive. Therefore, if ω denotes a fourth root of $-\Omega^2$ expressible in powers of Ω^2, ω may be taken real. If now ϕ is a real solution of the above equation, we have

$$\omega^{-1}\check{\phi}\,\omega\,\frac{\Omega}{\omega^2}\,\omega\,\phi\,\omega^{-1} = \frac{\Omega}{\omega^2},$$

in which $\omega\,\phi\,\omega^{-1}$ and $\frac{\Omega}{\omega^2}$ are real. Therefore, by the preceding theorem,

$$\begin{aligned}\omega\,\phi\,\omega^{-1} &= \left(\frac{\Omega}{\omega^2} - \Upsilon'_\alpha\right)^{-1}\left(\frac{\Omega}{\omega^2} + \Upsilon'_\alpha\right)\left(\frac{\Omega}{\omega^2} - \Upsilon'_\beta\right)^{-1}\left(\frac{\Omega}{\omega^2} + \Upsilon'_\beta\right)\\ &= \omega\,(\Omega - \Upsilon_\alpha)^{-1}(\Omega + \Upsilon_\alpha)\,(\Omega - \Upsilon_\beta)^{-1}(\Omega + \Upsilon_\beta)\,\omega^{-1},\end{aligned}$$

in which Υ'_α, Υ'_β, and therefore $\Upsilon_\alpha = \omega\,\Upsilon'_\alpha\,\omega$, $\Upsilon_\beta = \omega\,\Upsilon'_\beta\,\omega$, are real symmetric matrices.

Thus it appears that the group of real solutions of the equation $\check{\phi}\,\Omega\,\phi = \Omega$ can be generated by the Cayleyan solutions of this group, that is, by the totality of expressions of the form $(\Omega - \Upsilon)^{-1}(\Omega + \Upsilon)$, in which Υ is a real symmetric matrix such that $|\,\Omega - \Upsilon\,| \neq 0$.

§ 2. *Bilinear Form, neither Symmetric nor Alternate.*

1. The problem to determine the most general solution of the equation $\check{\phi}\,\Omega\,\phi = \Omega$, in which Ω is neither symmetric nor skew symmetric, may, provided neither ± 1 is a latent root of $\Omega\,\check{\Omega}^{-1}$, be reduced to the solution of two algebraic equations of the nth degree.

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* See *ante*, p. 178.

Thus, let

$$2\,\Omega_0 = \Omega + \breve{\Omega},\ \ 2\,\Omega_1 = \Omega - \breve{\Omega}.$$

Then, if ϕ satisfies the above equation, we have, as shown by Cayley,

$$\breve{\phi}\,\Omega_0\,\phi = \Omega_0,\ \ \breve{\phi}\,\Omega_1\,\phi = \Omega_1;$$

and conversely.

If neither ± 1 is a latent root of $\Omega\,\breve{\Omega}^{-1}$, then $|\,\Omega_0\,| \neq 0$, $|\,\Omega_1\,| \neq 0$. Since $|\,\Omega_0\,| \neq 0$, Ω_0 has a square root expressible by Sylvester's formula in powers of Ω_0. For the determination of this square root the solution of the algebraic equation $|\,\Omega_0 - g\,| = 0$ is requisite. If $\Omega_0^{\frac{1}{2}}$ denotes any symmetric square root of Ω_0, the equation $\breve{\phi}\,\Omega_0\phi = \Omega_0$ may be written

$$(\Omega_0^{\frac{1}{2}})^{-1}\,\breve{\phi}\,\Omega_0^{\frac{1}{2}}\cdot\Omega_0^{\frac{1}{2}}\,\phi\,(\Omega_0^{\frac{1}{2}})^{-1} = 1,$$

which, if $\psi = \Omega_0^{\frac{1}{2}}\,\phi\,(\Omega_0^{\frac{1}{2}})^{-1}$, becomes

$$\breve{\psi}\,\psi = 1.$$

Therefore, the most general expression for the matrix ϕ satisfying the above equation is

$$\Omega_0^{-\frac{1}{2}}\,\psi\,\Omega_0^{\frac{1}{2}},$$

in which ψ is an arbitrary orthogonal matrix.

If $\breve{\phi}\,\Omega\,\phi = \Omega$, we must also have $\breve{\phi}\,\Omega_1\,\phi = \Omega_1$. Therefore,

$$\Omega_0^{\frac{1}{2}}\,\breve{\psi}\,\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}}\,\psi\,\Omega_0^{\frac{1}{2}} = \Omega_1,$$

$$\breve{\psi}\,\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}}\,\psi = \Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}}.$$

But (9) § 1 ψ is given by the product of the three matrices.

$$\begin{aligned}
&(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} - \Upsilon'_\alpha)^{-1}\,(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} + \Upsilon'_\alpha)\\
&\qquad = \Omega_0^{\frac{1}{2}}\,(\Omega_1 - \Omega_0^{\frac{1}{2}}\,\Upsilon'_\alpha\,\Omega_0^{\frac{1}{2}})^{-1}\,(\Omega_1 + \Omega_0^{\frac{1}{2}}\,\Upsilon'_\alpha\,\Omega_0^{\frac{1}{2}})\,\Omega_0^{-\frac{1}{2}},\\
&(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} - \Upsilon'_\beta)^{-1}\,(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} + \Upsilon'_\beta)\\
&\qquad = \Omega_0^{\frac{1}{2}}\,(\Omega_1 - \Omega_0^{\frac{1}{2}}\,\Upsilon'_\beta\,\Omega_0^{\frac{1}{2}})^{-1}\,(\Omega_1 + \Omega_0^{\frac{1}{2}}\,\Upsilon'_\beta\,\Omega_0^{\frac{1}{2}})\,\Omega_0^{-\frac{1}{2}},\\
&(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} - \Upsilon'_\gamma)^{-1}\,(\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}} + \Upsilon'_\gamma)\\
&\qquad = \Omega_0^{\frac{1}{2}}\,(\Omega_1 - \Omega_0^{\frac{1}{2}}\,\Upsilon'_\gamma\,\Omega_0^{\frac{1}{2}})^{-1}\,(\Omega_1 + \Omega_0^{\frac{1}{2}}\,\Upsilon'_\gamma\,\Omega_0^{\frac{1}{2}})\,\Omega_0^{-\frac{1}{2}},
\end{aligned}$$

in which Υ'_α, Υ'_β, Υ'_γ, are commutative with $\Omega_0^{-\frac{1}{2}}\,\Omega_1\,\Omega_0^{-\frac{1}{2}}$.

If we put $\Upsilon_\alpha = \Omega_0^{\frac{1}{2}}\,\Upsilon'_\alpha\,\Omega_0^{\frac{1}{2}}$, $\Upsilon_\beta = \Omega_0^{\frac{1}{2}}\,\Upsilon'_\beta\,\Omega_0^{\frac{1}{2}}$, $\Upsilon_\gamma = \Omega_0^{\frac{1}{2}}\,\Upsilon'_\gamma\,\Omega_0^{\frac{1}{2}}$, we have for $\phi = \Omega_0^{-\frac{1}{2}}\,\psi\,\Omega_0^{\frac{1}{2}}$ the expression

$$(\Omega_1 - \Upsilon_\alpha)^{-1}\,(\Omega_1 + \Upsilon_\alpha)\ \ (\Omega_1 - \Upsilon_\beta)^{-1}\,(\Omega_1 + \Upsilon_\beta)\,(\Omega_1 - \Upsilon_\gamma)^{-1}\,(\Omega_1 + \Upsilon_\gamma).$$

Therefore, the group of solutions of the equation $\breve{\phi}\Omega\phi = \Omega$ is a sub-group of the equation $\breve{\phi}\,\Omega_1\,\phi = \Omega_1$, generated by the totality of expressions

$$(\Omega_1 - \Upsilon)^{-1} (\Omega_1 + \Upsilon),$$

in which the symmetric matrix Υ is subject to the condition that $\Omega_0^{-\frac{1}{2}} \Upsilon \Omega_0^{-\frac{1}{2}}$ is commutative with $\Omega_0^{-\frac{1}{2}} \Omega_1 \Omega_0^{-\frac{1}{2}}$, and is such that the determinant of $| \Omega - \Upsilon | \neq 0$.

To find the most general skew symmetric matrix $\Omega_0^{-\frac{1}{2}} \Upsilon \Omega_0^{-\frac{1}{2}}$ commutative with $\Omega_0^{-\frac{1}{2}} \Omega_1 \Omega_0^{-\frac{1}{2}}$ requires in general the solution of an algebraic equation of the *n*th degree.*

Again, since ψ is the product of three orthogonal matrices of which —1 is not a latent root and which are commutative with Ω_1, the group of solutions of the equation $\breve{\phi} \Omega \phi = \Omega$ is a sub-group of the group of solutions of the equation $\breve{\phi} \Omega_0 \phi = \Omega$ generated by the totality of expressions

$$\Omega_0^{-\frac{1}{2}} (1 - \Upsilon)^{-1} (1 + \Upsilon) \Omega_0^{\frac{1}{2}} = (\Omega_0 - \Omega_0^{\frac{1}{2}} \Upsilon \Omega_0^{\frac{1}{2}})^{-1} (\Omega_0 + \Omega_0^{\frac{1}{2}} \Upsilon \Omega_0^{\frac{1}{2}}),$$

in which Υ is a skew symmetric matrix commutative with Ω_1 and such that the determinant of $\Upsilon - 1$ is not zero.

The sub-group consisting of the orthogonal solutions of the equation $\breve{\phi} \Omega \phi = \Omega$ is the group of orthogonal matrices commutative with Ω_0 and Ω_1. It has been shown that the group of orthogonal matrices commutative with Ω_1 is generated by the totality of expressions $(1 - \Upsilon)^{-1} (1 + \Upsilon)$ in which Υ is a skew symmetric matrix commutative with Ω_1. This group contains only proper orthogonal matrices; and it is readily proved that the group of orthogonal matrices commutative with Ω_0 is generated by the totality of expressions $(1 - \Upsilon)^{-1} (1 + \Upsilon)$ in which Υ is commutative with Ω_0 and such that $| \Upsilon - 1 | \neq 0$. Therefore the group of orthogonal solutions of the equation $\breve{\phi} \Omega \phi = \Omega$ can be generated by the totality of orthogonal matrices of which —1 is not a latent root that are commutative with Ω; that is, by the totality of expressions $(1 - \Upsilon)^{-1} (1 + \Upsilon)$, in which Υ is a skew symmetric matrix commutative with Ω and such that $| \Upsilon - 1 | \neq 0$.

Clark University, Worcester, Mass.

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* If the fundamental syzygy in $\Omega_0^{-\frac{1}{2}} \Omega_1 \Omega_0^{-\frac{1}{2}}$ is of order equal to the order of this matrix, the most general matrix commutative with $\Omega_0^{-\frac{1}{2}} \Omega_1 \Omega_0^{-\frac{1}{2}}$ is a rational integral function of this matrix. This is the case if the roots of the equation $| \Omega - g \breve{\Omega} | = 0$ are all distinct. The fundamental syzygy in any matrix ϕ is the polynomial in powers of ϕ of lowest order that vanishes.

XVII.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, NO. VII.

FURTHER NEW AND IMPERFECTLY KNOWN PLANTS COLLECTED IN MEXICO BY C. G. PRINGLE IN THE SUMMER OF 1893.

By B. L. Robinson and J. M. Greenman.

Presented April 11, 1894.

Polygala puberula, Gray, var. **ovalis**. Low, 1–3 inches in height: leaves all oval or slightly obovate, very obtuse, apiculate, 6–8 lines long, half to two thirds as broad, purplish beneath: racemes scarcely exceeding the leaves, more closely flowered than in the type; pedicels ascending. — Collected in damp hollows of hills near Guadalajara, Jalisco, 22 May, 1893 (no. 4472).

Anoda hastata, Cav. A form apparently of this species, but with flowers orange-yellow instead of purple, has been collected by Mr. Pringle in the barranca of Tequila, 2 October, 1893 (no. 5454). Except the color, however, no characteristics in the specimens in question form satisfactory specific or even varietal distinctions.

Sida caudatifolia. Stem terete, over two feet in height, tomentulose, and villous with spreading white hairs leaves ovate, cordate, serrate-dentate, long-attenuate, somewhat pruinous-pubescent and soft to the touch above, paler and velvety tomentose beneath, about 9-nerved, 5 inches long, 2–3 inches broad, upon villous petioles of nearly equal length; floral leaves lanceolate to linear: lower flowers axillary and solitary; the upper paniculate; pedicels 9–18 lines long: calyx slightly angulate, densely pubescent, not accrescent; segments ovate, acuminate: petals yellow, 4–5 lines long: carpels 5, slightly and bluntly beaked at the apex. — Collected in the barranca of Tequila, 13 October, 1893 (no. 5445).

Dalea filiciformis. Root thick, fusiform, yellow: stems several, much branched, shrubby below, glandular-punctate above: leaves delicate, 8–10 lines in length, 17–37 foliate; leaflets very small, ⅔ line in length, oblong, rounded at the apex and base, glabrous, glandular-punctate beneath: spikes elongated, terminal, very loosely flowered; peduncles 2–2½ inches in length; floral rachises as long or longer; bracts ovate, acuminate, glabrous, caducous, 3 lines long: calyx very villous, resinous-dotted between the ribs, 3–4 lines long; the teeth filiform, plumose, much longer than the tube: corolla light-colored with purple glandular dots; keel 4 lines long. — Collected upon limestone hills, Villar, San Luis Potosi, 14 September, 1893 (no. 5472).

Dalea unifoliata. Slender, smooth, annual, with spreading branches from near the base, a span to a foot in height. stem glandular-punctate: leaves strictly unifoliate; petioles 3–4 lines long; leaflet broadly ovate, truncate or subcordate at the base, rounded at the apex, glandular-crenate; the larger ones 6–7 lines long, equally broad: racemes terminal or nearly so, 2–3 inches long; pedicels ½ line in length: calyx turbinate, finely pubescent with curved hairs along ten prominent nerves, and ciliate upon the margin, nearly 2 lines long: vexillum small, white, much exceeded by the violet wings and keel; the latter about 2 lines in length: ovary apparently but one-ovuled. — Collected in Orizaba by F. Müller, August, 1853 (no. 663), and in dry, thin soil, barranca of Tequila, Jalisco, by Mr. Pringle, 6 October, 1893 (no. 4585). A very attractive and well marked species, which has long been represented in several herbaria by Müller's specimens, for which, we find no description.

Tephrosia macrantha. Tall, 6–12 feet in height: branches angled and strongly ribbed, fulvous-tomentose as well as the peduncles and petioles: upper leaves 3–5 inches in length; leaflets 17–23, narrowly elliptic to lance-oblong, obtusish to cuneate at the base, acutish or obtuse and often apiculate at the apex, grayish with a fine appressed pubescence upon both surfaces, tawny upon the midrib beneath, 11–14 lines long, 3 lines broad; petiolules 1 line long: panicles large terminal, of numerous spreading pedunculate racemes (6–9 inches in length); bracts linear-filiform, 4 lines in length, 3-nerved, appressed silky-pubescent; pedicels ascending, 2½ lines long, grouped by 2's and 3's: calyx finely pubescent, campanulate, 3 lines in length, parted to the middle; teeth slender, lanceolate, attenuate: corolla fully 1 inch in length, in the dried specimens lilac; standard orbicular, streaked with green, its slender claw exserted from the shallow tube of the calyx; alæ oblong, oblique at the base; parts of the keel obtusely auricled: free stamen biglandular at the base, as is also the stamineal tube: pods 2–2¼ inches long, deflexed, falcate, tipped with the attenuate style, finely pubescent, 5–10 seeded. — Collected on hills near

Tequila, 5 October, 1893. A highly ornamental species, distinguished by its large flowers, and figured in 'Garden and Forest,' vii. 175.

COURSETIA MOLLIS. A low shrub, 3–6 feet high: branches striate, glabrate, gray; branchlets and petioles glandular-tomentose: leaves 15–21-foliate, 4–7 inches long; leaflets elliptic-oblong, rounded at the apex, apiculate or retuse, soft cinereous-pubescent, 8–11 lines long, 3½–5 lines broad; youngest leaves white, silky-villous; stipules subulate, 1½–2 lines long, villous, persistent as short rigid spines: racemes shorter than the leaves, 1½–3 inches long, few-flowered; pedicels about three lines long: calyx deeply and subequally 5-cleft, 4½–6 lines long, glandular; segments lanceolate acute: corolla 7–9 lines long; the orbicular standard reddish brown in a dried state; the wings and keel yellow: ovary shortly stipitate, glandular-tomentose, about 12-ovuled; pod pubescent, 2–2½ inches long, 2 lines broad, about 7-seeded. — Collected in the barranca of Beltran, 5 June, 1893 (no. 5491).

DESMODIUM SPIRALE, DC. The numerous and varied forms of *Desmodium* which in their technical characters closely agree with this species form one of the most puzzling groups of the genus. A fairly extensive series of specimens from South America, West Indies, and especially from Mexico and New Mexico, goes far to confirm the view expressed by Bentham (Flora Brasiliensis, xv. pt. 1, 105, 106, and repeated by Grisebach, Fl. Brit. W. I. 188) that these closely related forms are better regarded as constituting one polymorphous species. Nevertheless, it is desirable that the chief tendencies of variation should be indicated. The original descriptions of *Desmodium* (*Hedysarum*) *spirale* by Swartz (Prodr. 107), and De Candolle (Prodr. ii. 332), indicate that the type of the species had trifoliate leaves with roundish-ovate leaflets. Of this form specimens from the following localities have been seen: Toscano, Cuba, *Wright* (no. 2319); Jamaica, *Macfadyen;* Porto Rico, *Sintensis* (no. 1981); Tovar, Venezuela, *Fendler* (nos. 1785, 1786); Guayaquil, *Hartweg* (no. 650, *D. sylvaticum*, Benth.); Costa Rica, *Oersted;* Brazil, *Burchell* (no. 9092); and Jalisco, *Pringle* (no. 3882). In all these specimens the pods are very slender and strongly contorted, the segments being only ¾–1 line broad. From this form the following varieties may be distinguished: —

Var. TRANSVERSUM. Low, 6–10 inches high, with spreading branches: leaves small, all or the lower unifoliate; the single terminal leaflets being transversely rhombic, 4–8 lines broad, two thirds as long; the upper leaves with ovate-oblong leaflets: pod very slender and strongly twisted, as in the type. — Collected by Mr. Pringle on bluffs of a barranca near Guadalajara, 26 September, 1891 (no. 5179), and again on hillsides near the same locality, 6 September, 1893 (no. 4522).

Var. EXIGUUM. Very similar to the preceding, but the leaflets of the 1–3-foliate upper leaves almost linear: segments of the pod a little broader. — *D. exiguum*, Gray, Pl. Wright. ii. 46; Torr. Bot. Mex. Bound. 57. — New Mexico, *Wright* (no. 1010); Santa Cruz, Sonora, *Thurber* (no. 933), and San Jose del Cabo, Lower California, *Brandegee* (no. 145). Although referred to *D. Neo-Mexicanum*, Gray, by Dr. Watson, Bibl. Index, 217, this variety appears to us distinct from that species which has an essentially flat pod and leaflets usually narrow throughout.

Var. ANNUUM. Leaves unifoliate (rarely one or two trifoliate): leaflets broadly ovate. rather large, 1½ inches long: segments of the pod 1½–1¾ lines broad. — *D. annuum*, Gray, Pl. Wright. ii. 46. Referred to *D. spirale* by Watson, Bibl. Index, 218. — New Mexico, *Wright*, (no. 1009 a); Sonora, *Thurber* (no. 934).

Var. BIGELOVII. Leaves chiefly trifoliate, with oblong-lanceolate leaflets (about 1–1½ inches long), one or two of the lowest leaves unifoliate with a small broad leaflet: segments of the pod 1½ lines or more in breadth, slightly twisted. — *D. Bigelovii*, Gray, Pl. Wright. ii. 47. *D. Neo-Mexicanum*, var. *Bigelovii*, Wats. Bibl. Index, 217; referred to *D. spirale* by Grisebach, Fl. Brit. W. I. 188. — New Mexico, *Wright* (no. 1012); Sonora, *Thurber* (no. 955); W. Texas, *Havard* (no. 22); San Luis Potosi, *Parry & Palmer* (no. 181), *Schaffner* (no. 796 in part); S. Arizona, *Rothrock* (no. 663) Lemmon (no. 539); Mexican Bound. Surv. (no. 277); Chihuahua, *Pringle* (no. 612). This variety differs from *D. Neo-Mexicanum* in its broader leaflets and in the somewhat twisted segments of its legumes; from variety *transversum* it differs in its decidedly broader pods, as well as in its generally taller habit and larger leaflets.

PHASEOLUS MONOSPERMUS. Stem slender, twining, light-colored, sparingly pubescent with hooked hairs: stipules ovate, scarcely a line long; petioles slender, 1–1½ inches long; leaflets 3, deltoid-ovate, entire, membranaceous, green on both surfaces, narrowed to an obtuse and mucronate apex, subtruncate at the base, finely ciliated upon the margins and veins, 15–22 lines long, three fourths as broad; stipels minute, spreading: racemes 4–6 inches long; rachis pubescent, floriferous from below the middle; bracts ovate, obtuse, a line in length; pedicels twice as long, single or in pairs: flowers small. purplish: calyx about a line long, 5-toothed: vexillum 2 lines long, equally broad, retuse: ovary uniovulate; legume pendulous, somewhat trapezoidal, 1-seeded, membranous, acuminate at the apex, finely pubescent, ciliated on the margin, about half an inch long. — Collected in the barranca of Tequila, Jalisco, 13 October, 1893 (no. 5446). This species is exceptional in *Phaseolus* in possessing 1-seeded legumes, but, differing from this genus in no other regard, should doubtless be referred hither, especially since in the closely related *P. filiformis*, Benth., there are sometimes but two seeds in the pods.

VIGNA STROBILOPHORA, Rob. (Proc. Am. Acad. xxvi. 167.) Specimens of this plant collected in a barranca near Guadalajara, 25 August, 1893 (no. 4503), furnish the following supplementary characters: stems woody, an inch or more thick, climbing to the tops of shrubs and trees: legumes smooth, 4 inches long, half an inch in breadth, acuminate; seeds ellipsoidal, dark purple, mottled, almost black. This plant has been figured recently in 'Garden and Forest,' vii. 155.

CÆSALPINIA MEXICANA, Gray, var. PUBESCENS. Branchlets and both surfaces of the leaves when young soft-pubescent: petals beautifully ciliolate with stipitate glands: pod rather short and broad, free from the punctation commonly if not always present in the typical form. — Collected on dry hills near Zapotlan, 25 May, 1893 (no. 5467).

SCHIZOCARPUM PARVIFLORUM. Stems very slender, furrowed, finely pubescent; internodes elongated: leaves cordate-ovate in outline, denticulate, green and sparsely appressed-pubescent above, slightly paler and more densely appressed-pubescent beneath, varying from 3–5-toothed to deeply 3-lobed; lobes apiculate, the terminal one often considerably exceeding the others: tendrils unequally 2-branched: peduncles pubescent, 3 lines to an inch long: free lobes of the adnate calyx filiform, 1–1¾ lines long: the yellow campanulate corolla 8–12 lines in length, finely glandular-pubescent upon the outer surface, soft pubescent within, ciliolate upon the margin; segments ovate, obtusish, sometimes apiculate, 3(–5)-nerved: filaments about 2 lines in length, equalling the anthers: fruit flask-shaped, nearly 2 inches in length, puberulent. — Collected on talus of cliffs, barranca of Tequila, Jalisco, 3 October, 1893 (no. 4555). Very similar in habit to *S. filiforme*, Schrad., but with flowers about half as large.

COULTEROPHYTUM LAXUM, Rob. (Proc. Am. Acad. xxvii. 169.) A younger specimen, collected in the barranca of Tequila, 6 July, 1893 (no. 5537), shows the following additional characters: flowers yellowish-green; petals broad at the base, abruptly contracted to a slender, incurved tip.

CRUSEA CORONATA. Low: stem purple with spreading branches, nearly or quite smooth: leaves linear, smooth, acute, 5–10 lines long, 1 line wide; margins revolute; stipular sheaths very short, bearing on each side 3–4 often ciliated bristle-formed teeth: flowers sessile, axillary and terminal, single or less frequently in pairs subtended by two bracts with their bristle-toothed stipular sheath: calyx segments linear, acute, 2–2½ lines long: corolla very small, only ¾ line long, 4-toothed at the summit: stamens included, inserted near the base of the corolla tube; filaments slender: stigma 2-cleft; divisions of the fruit short, columnar, minutely hispid, slightly enlarged at the summit and crowned with a row of spreading bristles. — Collected on dry, rocky soil, Tequila, 3 October, 1893 (no. 5424). This species bears a habital resemblance to *C. subulata*, Hook. & Arn., but is well characterized by its crowned fruit.

GYMNOLOMIA PATENS, Gray, var. ABBREVIATA. Stem 3–5 feet high: petioles much shorter than in the type, about 2 lines in length: heads rather closely grouped at the ends of the branches. — Collected in ravines near Tequila, Jalisco, 21 September, 1893 (no. 4595).

GYMNOLOMIA RUDIS, Gray, var. MINOR. Leaves elliptic, smaller than in the type, 2 inches long, ¾ inch broad, reflexed: heads also smaller, but 8 lines broad. — Collected on rocky hills near Tequila, Jalisco, 7 October, 1893 (no. 4584).

VIGUIERA PRINGLEI. Shrubby, 5–10 feet high, scabrous: leaves all but the uppermost opposite, elliptic or ovate, of firm texture, entire or somewhat denticulate upon the strongly revolute margins, 3-nerved and prominently reticulated beneath, 2½ inches long, 12–14 lines broad, green and very rough upon both surfaces, sessile or subsessile, obtuse and mucronate or acutish at the apex, obtuse at the base, translucent-punctate: heads exclusive of the rays about 8 lines in diameter, corymbose; pedicels becoming an inch long in fruit: involucral scales imbricated in about 5 series, linear-oblong, acute, often apiculate, thickened in the middle, the outer regularly shorter; flowers yellow; ligules 10–12, a half-inch in length, 2 lines broad, shortly 3-toothed at the apex: achenes strongly flattened, black, 2 lines long, silky-villous especially upon the margins, with upwardly pointed hairs; aristæ 2, about half the length of the achene; intermediate scales several; empty ray achenes triangular. — Collected in fruit by Mr. Pringle on hills near Zapotlan, 12 May, 1893 (no. 4365). Flowering specimens of the same plant, collected by Dr. Edward Palmer, at Tepic, 5 January to 6 February, 1892 (no. 1979), have been very kindly sent to us by Dr. J. N. Rose of the Department of Agriculture.

Encelia Mexicana, Mort. A noteworthy form of this species, collected in fields and copses about Tequila, September and October, 1893 (no. 4602), has ovate-deltoid unlobed leaves, slender petioles (entirely devoid of the clasping auricular appendages so common in the species), large and long-peduncled heads, elongated and very glandular involucral bracts less villous than in other specimens at hand. While different forms of this species certainly show striking differences in the features mentioned, a series of specimens show that these characters vary quite independently of each other, forming various combinations, so that varieties based upon them could have little more than formal value.

Coreopsis petrophiloides. Stem furrowed, light brown, nearly or quite glabrous, leafy above; branchlets angulate, slightly pubescent: leaves simple, lanceolate, acute, incised-serrate, glandular-punctate, 1½–3½ inches long, one third as broad, slightly pubescent above, smooth and very pale beneath: heads nearly ½ inch long, rather short-peduncled, aggregated in terminal corymbose inflorescences: floral leaves reduced to short linear-oblong entire bracts: outer scales much shorter than the inner; the latter oblong, obtusish: rays deep yellow, ½ inch in length: achenes bi-aristate, strongly ciliated upon the margins, silky-villous upon one face, glabrous upon the other (toward the chaff). — Collected on the Nevado de Colima, 22 May, 1893 (no. 5508). In habit, inflorescence, and heads, very close to *C. petrophila*, Gray, but with undivided leaves much paler beneath.

Perezia Pringlei. Stem strict, rather stout, herbaceous, pubescent, purplish, 3 feet or more in height: leaves harsh, oblong, obtuse but mucronulate, sessile, cordate-clasping, doubly spinose-dentate, glabrous, and strongly reticulate-veined above, finely pubescent beneath, 3–5 inches long, 1–2 inches broad; the upper ones gradually smaller and acute: heads large, terminal upon short branches springing from the upper axils, and together forming a racemiform inflorescence a foot in length: involucral bracts regularly imbricated in 5–6 series, ovate to lanceolate, acute to acuminate, purplish upon the exposed portion; the inner ones nearly an inch in length: flowers about 50 in each head: corollas purple, 7 lines long. — Collected on hills near Morelia, Michoacan, 22 October, 1893 (no. 5464). This species has somewhat the foliage of *P. rigida*, Gray, but heads much larger and differently disposed.

Gonolobus angustilobus. Branches slender, twining, pulverulent, and covered with roughish, spreading pubescence: petioles about an inch long, pubescent; leaves ovate, acuminate, cordate with a deep narrow sinus, appressed-pubescent above, paler and somewhat pubescent beneath especially upon the veins, 2–2½ inches long, two thirds as broad; margins finely ciliated: peduncles filiform, half to two thirds as long as the petioles, 1-flowered; pedicels about 5 lines long: calyx segments ovate, acute, 2–3 lines long; margin strongly ciliated: corolla rotate, green, a little over an inch in breadth; segments almost linear, narrowed to an obtuse apex, inconspicuously striate, but not reticulated, glabrous on the outside, white-bearded within, near the throat: corona fuscous. — Collected in the barranca of Tepic, 10 October, 1893 (no. 5458).

GONOLOBUS JALISCENSIS. Branches densely and retrorsely pubescent: leaves narrowly oblong, attenuate, abrupt or cordate at the base, appressed-pubescent above, tomentose beneath, 15–20 lines long, 2½–5 lines broad; petioles pubescent, 4–5 lines in length: peduncles short, nodose, 9–14-flowered; pedicels 4 lines long, finely pubescent: calyx segments ovate-lanceolate, acutish, densely pubescent, 1¼ lines in length: segments of the corolla ovate acutish, 1½ lines long, somewhat reflexed, pubescent on the outside, bearded on the upper surface with short white hairs, yellowish green, somewhat striated: crown orange: upper surface of the column brown: follicle fusiform, attenuate; outer surface roughened with fine longitudinal folds minutely pubescent; inner surface light yellow, smooth, and shining. — Collected on dry, rocky hills near Guadalajara, 21 June, 1893 (no. 4402).

GONOLOBUS DIADEMATUS, Edwards. This species, carefully described and figured in the Botanical Register, iii. t. 252 (1817), is referred to Mexico without more definite locality. So far as we know the plant has not since been collected, and its present rediscovery by Mr. Pringle in a barranca near Tepic, 10 October, 1893 (no. 5429), is thus of interest as establishing more accurately its geographic position. While corresponding in essential features to the original characterization and plate, the specimens at hand have 8–11-flowered peduncles, and somewhat larger leaves. The corolla turns nearly black in drying, and Mr. Pringle states that the fruit is distinctly pentangular.

PHYSALIS LEPTOPHYLLA. Stem slightly woody below, herbaceous above, striate, finely pubescent, more or less strongly geniculate, and with spreading branches: leaves ovate, entire, sharply acuminate, unequal, and not attenuate at the base, very delicate in texture, green and nearly glabrous upon both sides, 10 lines to 3½ inches long, two thirds as broad; margins finely ciliated; petioles ½–2½ inches long, glandular-villous: flowers very small, commonly nodding, springing from the forks of the branches; peduncles but 1–2 lines long: calyx in anthesis 1½ lines long, glandular-villous; teeth short, ovate, acute: corolla apparently white, with dark spots at the base, 2–3 lines long: anthers greenish-blue: fruiting calyx about ½ inch in diameter. — First collected by Mr. W. G. Wright near Mazatlan, January, 1889 (no. 1252); then by Dr. Edward Palmer, at Alamos, September 16–30, 1890 (no. 709, mentioned by Dr. Rose, Contr. Nat. Herb. i. 108), and finally collected by Mr. Pringle in the barranca of Tepic, 11 October, 1893. This species differs from any known to the authors in its very thin, quite entire, exactly ovate and sharply acuminate leaves, as well as in its small subsessile flowers. The following imperfectly described species may well be related: *P. geniculata*, Miers, which, however, is said to have obtusish leaves and peduncles equalling the petioles; *P. glabra*, Mart. & Gal., which also has peduncles equalling the petioles; and *P. minutiflora*, Moç. & Sesse, with repand acute pruinous leaves.

JACOBINIA STELLATA. Stellate-tomentose: stems ligneous, branched, light colored, not constricted about the nodes: leaves ovate-lanceolate, 1½–4 inches long, two fifths as broad, narrowed to an obtuse apex, cuneate at the base, paler beneath; petioles 5–8 lines long: inflorescences short, crowded, pedunculate in the upper axils, glandular-pubescent; bracts narrowly elliptic, cuneate, foliaceous, 5 lines long: calyx segments linear-oblanceolate, acutish, 1-nerved, 8 lines long, a line broad: corolla 1½ inches or more in length, slender, reddish purple; the lower lip spreading, 6 lines long; the upper erect, a little shorter: fruit glandular-pubescent, a little over a half an inch in length. — Collected under dry cliffs in the barranca of Tequila, 16 October, 1893 (no. 4573). Well characterized by its pubescence.

CARLOWRIGHTIA HAPALOCARPA. Rootstock horizontal, much branched: stems erect, or nearly so, 10–15 inches high, tomentulose and slightly hirsute, with a few longer spreading hairs: leaves short-petioled, ovate, acute, 1–1⅓ inches long, 9–12 lines broad, hirsute upon the veins and margin, paler beneath: flowers in pairs, forming loose subsimple terminal spikes; bracts minute: calyx glandular-pubescent; segments linear-oblong, acutish, 1–1½ lines long: corolla pale purple, nearly ½ an inch in length: anther cells slightly oblique: fruit tomentulose; seeds flat, black, finely tuberculate. — Collected on limestone hills, Villar, State of San Luis Potosi, 14 September, 1893 (no. 5471).

LIPPIA APPENDICULATA. Procumbent, much branched, appressed-pubescent, cinereous: stem short, somewhat ligneous, 1½–2 lines in diameter, covered with a light-colored cracked cortex; branches slender, flexuous, ascending, a span in length: leaves lanceolate in outline, pinnatifid, plicate, prominently veined beneath, 4–6 lines long, cuneate at the base; the tooth-like segments short, obtuse: peduncles axillary, 1–2 inches in length; spikes oblong, dense, 6–10(–22) lines long, 4 lines in diameter: bracts ovate-lanceolate, acute, ciliated, and pubescent, 1½ lines long: calyx 2-parted, persistent; segments entire or minutely 2-toothed: corolla purplish, much exserted, 2½ lines long, 5-lobed; the ventral lobe somewhat larger than the others: stamens 4, in pairs; the ventral ones with slender erect appendages springing from the connective and exceeding the anthers in length: style short; stigma strictly simple, oblique. — Collected in wet alkaline soil, Mapimi Desert, Durango, 25 November, 1893 (no. 4625). — An anomalous species with the 5-parted corolla and appendaged anthers of *Verbena*, but the 2-cleft calyx and entire oblique stigma of *Lippia*.

Cunila pycnantha. Stems slender, branching, herbaceous, or slightly ligneous, tomentulose: cortex light brown, peeling off. leaves ovate-lanceolate, long-acuminate, 1½–2½ inches long, nearly half as broad, rounded or subcordate at the base, short-petioled, serrate except at the base and apex, smooth and dull green above, much paler and glaucous beneath, somewhat tomentose upon the midrib and petiole: flowers very numerous, small, not at all verticellate, but disposed in dense terminal capitate cymes: corolla pubescent upon the outer surface, 2 lines long, little exceeding the pubescent calyx. — Collected on Nevado de Colima, Jalisco, 7,000 feet, 22 May, 1893 (no. 5511). Well characterized by the dense terminal inflorescences, which give the plant a Eupatorium-like habit.

Salvia Pringlei. Shrub, 3–6 feet high, stems essentially smooth, finely striate, branching: leaves ovate, shortly acuminate, rounded or abrupt at the base, serrate, a little over 2 inches in length, 1½–2 inches in breadth, glabrous upon both surfaces; petioles 4–6 lines in length: spikes dense, terminal on the branches, 2–3 inches long; bracts ovate, acuminate, ciliated, and somewhat pubescent, 6 lines long, rather persistent: calyx tubular, 8 lines long, ciliated, pubescent within, 10-ribbed, becoming corrugated and compressed at the throat; the upper lip ovate, acuminate, entire; the lower lip bifid: corolla rose-purple, 1½ inches long; the upper segment very pubescent, ½ inch in length; the lower spreading, about equal in length. — Collected under cliffs of the barranca of Tequila, 2 October, 1893 (no. 4564).

Euphorbia delicatula, Boiss. This species was described from a Mexican specimen in the herbarium of Pavon, but without exact locality. The plant has now been rediscovered by Mr. Pringle on shaded ledges in the barranca of Tequila, 14 October, 1893 (no. 4550), thus definitely establishing its geographical position. We are indebted to M. Autran of the Boissier Herbarium for a positive identification of Mr. Pringle's specimens with the type. Some of the leaves show a slight tendency to be 3-lobed and somewhat repand.

EUPHORBIA JALISCENSIS. Glabrous and somewhat glaucous: stem stout, erect, dichotomous, striate: leaves panduriform, dentate near the apex and base, obtuse, paler beneath, 2½ inches long, 1½–2 inches broad, narrowed at the base; petioles 8–10 lines long, flat, striate, purple above and with narrow green margins: glands 4, oblong; appendages narrow, green, 2-parted; divisions bluntly toothed: segments of the involucre fimbriated: capsule large, short-oblong, glabrous, 3 lines long, 2½ lines broad; seeds columnar, tetragonal, mottled, 1½ lines long; caruncle conspicuous, cup-shaped. — Collected in the barranca of Tequila, 26 September, 1893 (no. 4608). A plant with much the habit of *E. Francoana*, Boiss., and *E. cuphosperma*, Boiss., as well as some forms of *E. heterophylla*, L. From all these it is distinguished by its considerably larger capsules.

PHYLLANTHUS TEQUILENSIS. Branches subterete, with a reddish-brown, scaly bark; branchlets more or less distinctly angled: leaves distichous, large, ovate-elliptic, rounded to acute at the apex, rounded at the base, smooth and glaucous upon both surfaces, paler beneath; the larger ones about 4 inches long, 3 inches broad; veins white, slightly prominent beneath; petioles 2 lines long; stipules oblanceolate, obtusish at the apex, cuneate at the base, 4–5 lines long, narrowly white-margined, deciduous: staminate inflorescences chiefly axillary, cymose or cymose-paniculate, many flowered, 1–2 inches long; branches filiform; pedicels 1–1½ lines long; fertile inflorescences terminal upon short branches, fewer flowered; pedicels a little thicker and longer: calyx of the staminate flower 6-parted; segments broadly oblong, rounded at the apex, inconspicuously pinnately veined, 1 line long; glands 6, often somewhat united into pairs, transversely elliptical, crenate: stamineal column scarcely developed, not at all produced beyond the anthers; anthers only two, 2-celled, transversely dehiscent: calyx of the fertile flower 6–7-parted; segments 1½ lines long; glandular cup 6-7-lobed: styles 3, shortly bifid; mature capsule depressed-globose, shallowly 3-lobed, glabrous, reticulated, 1½ inches in diameter, excavated at the base; seeds ovate in outline, finely striated, 4 lines long. — Collected upon hills about Tequila, Jalisco, 2 July and 2 October, 1893 (no. 5490). This species is reluctantly added to the group of large-leaved members of *Euphyllanthus.* It differs from *P. glaucescens,* HBK., as described by Kunth and Müller, Arg., in its shorter petioles, smaller leaves, and in the very different form of the stipules; from *P. adenodiscus,* Müll., Arg., in the form of the glands in the sterile flower and in the absence of any conical production of the stamineal column; from *P. laxiflorus,* Benth., in its much shorter inflorescences, as well as in its leaves, abrupt, not acute, at the base. From all these species it also differs in having definitely two and not three stamens.

ACALYPHA ERUBESCENS. An erect, pubescent annual, 6 inches to one foot in height: stems terete, purple, branched, villous with spreading white hairs; lower branches spreading, elongated: leaves ovate, crenate-serrate, obtuse, rounded at the base, 9–14 lines long; petioles 4–7 lines long: sterile spikes small, about 3 lines long on peduncles of nearly equal length; fertile spikes terminal and axillary, dense, short, cylindric, sessile, becoming reddish, 6 lines long, 4 lines in diameter; the lateral ones somewhat smaller; bracts 1-flowered, subequally 7-toothed, villous-pubescent: styles 3, undivided; ovary villous above; seeds ovoid, smooth, black, with a white caruncle. — Collected on limestone hills near Villar, 14 September, 1893 (no. 4538).

TRAGIA AFFINIS. Stems slender, elongated, flexuous as though twining, finely striated, densely pubescent: stipules 1¼ lines long; leaves ovate, acute, crenate-serrate, cordate with a deep rounded sinus, green and appressed-pubescent above, paler and more densely pubescent beneath, 2–2½ inches long, 15–20 lines broad; petioles ¾–1 inch in length: racemes loosely flowered, 2½ inches or less in length: calyx of the fertile flower with segments oblong, rounded at the apex, nearly or quite glabrous: capsule depressed globose, hirsute, 3–4 lines in diameter. — Collected in the barranca of Guadalajara, 17 October, 1893 (no. 5474). This plant has the whole habit and many of the technical characters of *T. macrocarpa,* Willd. It differs, however, in its shorter stipules and in the finer and more crenate serration of its leaves, those of *T. macrocarpa* being rather deeply and sharply serrate-dentate.

AGAVE POTOSINA. Roots thickened, fusiform; rootstock bulb-like, an inch or more in diameter, clothed with a thick layer of the broad, scarious, imbricated, persistent bases of the old leaves: fresh leaves few, 4–6; the foliar portion lance-linear, 6 inches long, about 5 lines broad, narrowed to a slender, unarmed tip; the narrow white margins bearing short, soft, spreading truncate or irregularly tipped teeth (less than a line in length): scape terete, glaucous, 1½–2 feet high, simple, floriferous above the middle; sterile scales about three, lanceolate, attenuate, slightly toothed, 1–1½ inches long; the floral similar, but much reduced above; raceme simple, loosely 12–20-flowered; pedicels 1–1½ lines long: tube of the perianth but 3 lines long, about equalling its narrowly oblong obtusish 9-nerved segments: stamens about 8 lines long: capsule very glaucous, subglobose, 5–6 lines in diameter. — Collected on calcareous mesas, Los Charcos, 2 July, 1891 (no. 3745). This number was distributed last year by an oversight as "*A. brunnea*, Wats. n. sp." Dr. Watson's species, however, was founded upon no. 2218, from which this is quite distinct as to perianth and capsule.

Sisyrinchium Pringlei. Acaulescent, strictly erect, 1–2 feet high: root a dense fascicle of short, thickened fibres: leaves acerose, pungent, 6–10 inches in length, with broad, sheathing bases; the latter persistent, cleaving into fibres: scapes simple, compressed: inflorescences single, terminal, an inch or more in length; spathe of two unequal bracts; the longer exceeding and the shorter about equalling the included flowers; spikelets 2 in each spathe, unequal, 3–5-flowered; flowers enclosed by oblong-lanceolate, acute, scarious-margined bractlets: perianth yellow; segments 4–5 lines long: capsule subglobose. — Collected on dry calcareous hills near Guadalajara, 4 September, 1893 (no. 4520).

PROCEEDINGS.

Eight hundred and fifty-ninth Meeting.

May 10, 1893. — ANNUAL MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read the following letters: from the Central Physical Observatory, St. Petersburg, announcing the celebration of the twenty-fifth anniversary of the Directorship of H. Wild, on the 10th of May; from C. de Candolle, announcing the death of his father, Alphonse de Candolle, a Foreign Honorary Member of the Academy, who died at Geneva on the 4th of April, in the eighty-seventh year of his age; from the Natural History Society of Rhineland, Westphalia, and Osnabrück, inviting the Academy to attend its fiftieth anniversary on the 24th of May; from the Physical-Mathematical Section of the University of Kasan, announcing its intention to establish a prize in the name of Lobatcheffsky for researches in mathematics, or to place a bust in the building of the University, and soliciting subscriptions; from the Smithsonian Institution, transmitting a circular relating to the Hodgkins Prize; and from Samuel Cabot, John Elliott Pillsbury, and John Henry Wright, accepting membership in the Academy.

The Corresponding Secretary presented the Report of the Council.

The reports of the Treasurer and the Librarian were read and accepted.

The following report was read: —

Report of the Rumford Committee.

The Committee, at its first meeting, October 28, 1892, appointed John Trowbridge, Chairman, and B. O. Peirce, Secretary.

Five meetings were held during the winter.

On November 11, 1892, the Committee recommended a grant of $250 to D. W. Shea of the Illinois University for the continuation of an investigation on light.

On December 2, 1892, it recommended a grant of $200 to B. O. Peirce for investigation on the propagation of heat; and a grant of $250 to H. A. Rowland of Johns Hopkins University for work on the solar spectrum and metallic spectra.

On January 11, 1893, the Committee voted to recommend to the Academy to replace a defective medal now in the possession of Alvan G. Clark by a perfect one of full weight. It was also voted to recommend to the Academy to give a bronze copy of the Rumford Medal to the Rumford Historical Society of Woburn, Massachusetts.

The merits of several possible candidates for the Rumford Medal have been considered during the year; but no award has been voted.

For the Committee,
JOHN TROWBRIDGE.

May 10, 1893.

In accordance with the recommendation of the Rumford Committee, it was

Voted, To appropriate two hundred and fifty dollars ($250) from the income of the Rumford Fund to H. A. Rowland of Johns Hopkins University for work on the solar spectrum and metallic spectra.

Voted, To refer the matters of replacing the defective medal in the possession of Alvan G. Clark, and of the presentation of a bronze copy of the Rumford Medal to the Rumford Historical Society, to the Rumford Committee, with full power.

On the recommendation of the Committee of Finance, it was

Voted, To make the following appropriations from the income of the general fund: —

For the library	$1,500
For publications	2,500
For the expenses of meetings . . .	200

On the motion of the Treasurer, it was

Voted, That the assessment for the ensuing year be five dollars.

The Committee on the proposed alteration of the Statutes presented a report, and it was

Voted, To amend the first section of Chapter VIII. of the Statutes by striking out the words, " to be held in the Hall of the Academy, in Boston." The section, as amended, reads as follows: —

"1. There shall be annually four stated meetings of the Academy; namely, on the second Wednesday in May (the Annual Meeting), on the second Wednesday in October, on the second Wednesday in January, and on the second Wednesday in March. At these meetings only, or at meetings adjourned from these and regularly notified, shall appropriations of money be made, or alterations of the statutes or standing votes of the Academy be effected."

The following gentlemen were elected members of the Academy: —

Sylvester Rosa Koehler, of Boston, to be a Resident Fellow in Class III., Section 4.

Frederick Remsen Hutton, of New York, to be an Associate Fellow in Class I., Section 4, in place of the late William P. Trowbridge.

Grove Karl Gilbert, of Washington, to be an Associate Fellow in Class II., Section 1, in place of the late John S. Newberry.

Friedrich August Kekulé, of Bonn, to be a Foreign Honorary Member in Class I., Section 3, in place of the late August W. von Hofmann

Maurice Lévy, of Paris, to be a Foreign Honorary Member in Class I., Section 4, in place of the late Marquis de Caligny.

Ludimar Hermann, of Königsberg, to be a Foreign Honorary Member in Class II., Section 3, in place of the late Sir Richard Owen.

Sir Joseph Lister, Bart., of London, to be a Foreign Honorary Member in Class II., Section 4, in place of the late Sir William Bowman, Bart.

James Bryce, of Oxford, to be a Foreign Honorary Member in Class III., Section 3, in place of the late Alfred, Lord Tennyson.

The annual election resulted in the choice of the following officers: —

Josiah P. Cooke, *President.*
Augustus Lowell, *Vice-President.*
Charles L. Jackson, *Corresponding Secretary.*
William Watson, *Recording Secretary.*
Eliot C. Clarke, *Treasurer.*
Henry W. Haynes, *Librarian.*

Councillors.

Charles R. Cross,
William R. Livermore, } of Class I.
Benjamin O. Peirce,

Henry P. Walcott,
Benjamin L. Robinson, } of Class II.
Henry W. Williams,

Lucien Carr,
Barrett Wendell, } of Class III.
Crawford H. Toy,

Rumford Committee.

Wolcott Gibbs,
John Trowbridge,
Erasmus D. Leavitt,
Benjamin O. Peirce,
Edward C. Pickering,
Charles R. Cross,
Amos E. Dolbear.

C. M. Warren Committee.

FRANCIS H. STORER,	SAMUEL CABOT,
THOMAS M. DROWN,	HENRY B. HILL,
CHARLES L. JACKSON,	LEONARD P. KINNICUTT,

ARTHUR M. COMEY.

Member of the Committee of Finance.

AUGUSTUS LOWELL.

The President appointed the following Standing Committees: —

Committee of Publication.

CHARLES L. JACKSON, WILLIAM G. FARLOW,
HORACE E. SCUDDER.

Committee on the Library.

BARRETT WENDELL, SAMUEL H. SCUDDER.
WILLIAM E. STORY,

Auditing Committee.

HENRY G. DENNY, AUGUSTUS LOWELL.

The following papers were presented by title: —

On the Occlusion of Gases by the Oxides of Metals. By Theodore William Richards and Elliot Folger Rogers.

On the Compound Acetates and Formiates of Cupriammonium. By Theodore W. Richards and Hubert Grover Shaw.

A Revision of the Atomic Weight of Barium. Second Paper: The Analysis of Baric Chloride. By Theodore William Richards.

The President appointed a Committee on the Custody of the Hall, consisting of the Recording Secretary, the Librarian, and Edward J. Young.

Eight hundred and sixtieth Meeting.

June 14, 1893. — MONTHLY MEETING.

The Academy met at the Physiological Lecture Room of the Harvard Medical School, Boston.

The PRESIDENT in the chair.

Harold C. Ernst explained the methods of investigation pursued in the study of bacteriology, illustrating his remarks with diagrams and lantern slides.

The attention of the Academy was then invited to an exhibit consisting of two main sections: —

1. Cultures of bacteria, including pathogenic and non-pathogenic organisms, in various nutrient media, each one, so far as possible, grown upon the standard media, in tube and plate culture, and the various cultures of the same organism grouped together and labelled with the common name; so that each one could be seen growing upon one or more of the following materials: nutrient gelatine (plain or with glycerine), nutrient agar-agar (plain or with glycerine), potato, bouillon, blood serum, milk, peptone, bread paste. Thus an opportunity was afforded for a comparative study of a number of varieties of bacteria under similar conditions.
2. Preparations placed under the microscope, showing the various appearances of the bacteria in tissues and in pure culture.

At the close of the lecture the President, after paying a just tribute to Dr. Ernst's interesting communication, proposed a vote of thanks, which was unanimously adopted.

Eight hundred and sixty-first Meeting.

October 11, 1893. — STATED MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters from J. Bryce, L. Hermann, and F. A. Kekulé, acknowledging their election as Foreign Honorary Members; from G. K. Gilbert and F. R. Hutton, acknowledging their election as Associate

Fellows; and from Sylvester R. Koehler, accepting Fellowship.

The following gentlemen were elected members of the Academy: —

Edward Salisbury Dana, of New Haven, to be an Associate Fellow in Class II., Section 1.

Samuel Louis Penfield, of New Haven, to be an Associate Fellow in Class II., Section 1, in place of the late Frederick A. Genth.

Jean Baptiste Édouard Bornet, of Paris, to be a Foreign Honorary Member in Class II., Section 2, in place of the late Alphonse L. P. P. de Candolle.

In accordance with the recommendation of the Committee on the Custody of the Hall, it was

Voted, To grant the use of the Hall of the Academy to the Colonial Society of Massachusetts on the third Wednesday of December, 1893, January, February, March, and April, 1894, after 3 o'clock P. M.

O. W. Huntington presented a paper entitled, "Further Observations upon the Occurrence of Diamonds in Meteorites."

On the motion of F. H. Storer, it was

Voted, That a Committee be appointed to consider changes in the statutes relating to the methods of electing officers.

On the motion of the Corresponding Secretary, it was

Voted, To meet on adjournment on the second Wednesday in November.

Eight hundred and sixty-second Meeting.

November 8, 1893. — ADJOURNED STATED MEETING.

The Academy met at the Engineering Building of the Massachusetts Institute of Technology, Boston.

The PRESIDENT in the chair.

The President announced the death of Moses Gerry Farmer, Resident Fellow, and of Benjamin Jowett, Foreign Honorary Member.

The Corresponding Secretary read letters from the Rumford Historical Association of Woburn, acknowledging the receipt of the bronze copy of the Rumford Medal presented by the Academy; from E. S. Dana and S. L. Penfield, acknowledging election as Associate Fellows; from the Anthropological Society of Washington, announcing the conditions of competition for its citizenship prizes; from the Natural History and Medical Society of Bonn, inviting the Academy to participate in its seventy-fifth anniversary festival; and from the Belgian Chemical Association, announcing an International Congress of Applied Chemistry, and inviting the Academy to send delegates.

The chairman of the C. M. Warren Committee made a brief report, recommending the appropriation of three hundred dollars to Charles F. Mabery for investigations on the American sulphur petroleums. This appropriation was voted by the Academy.

The President appointed a Committee on Methods of Electing Officers, consisting of the following gentlemen: Augustus Lowell, Chairman, F. H. Storer, Barrett Wendell, W. G. Farlow, and W. R. Livermore.

The Recording Secretary gave a brief account of the circumstances attending the award of the Massachusetts Charitable Mechanic Association's Grand Gold Medal at the exhibition in 1881 to Albert H. Emery. This medal, "for the exhibit most conducive to human welfare," was, at the request of the Association, bestowed by a committee of the Academy acting as judges.

Gaetano Lanza then explained and exhibited the Emery testing machine of 300,000 pounds' capacity, recently acquired by the Institute. This machine contains all the essential features of the 800,000 pounds testing machine built by Albert H. Emery, and now at the Watertown Arsenal.

The operation of this machine consisted in testing the compressive strength of a Virginia white-oak beam 13⅜ inches × 8¼ inch × 15 feet, which failed when a load of 176,000 pounds was applied.

Cross Breaking. — The next experiment consisted in breaking a yellow-pine beam 17 feet 6 inches between the supports, weighing 617 pounds, and having a cross-section of 16½ inches × 6 inches. The load was in the centre, suspended from a yoke weighing 102 pounds.

A micrometer was placed on the beam, and the deflections were measured as follows: —

Loads.	Micrometer Readings.	Difference.
2,000	.05595	.24160
7,000	.29755	

The modulus of elasticity corresponding to these deflections was 1,778,200 pounds per square inch.

The beam broke by tension and longitudinal shear, at a load of 38,000 pounds.

The corresponding calculated modulus of rupture, including the weight of the beam, was 7,409 pounds per square inch.

The maximum intensity of longitudinal shear was 287.9 pounds per square inch.

Torsion Testing Machine. — A two-inch Norway iron shaft, 6 feet long between the holders, was twisted 16 turns without breaking. This specimen, left over night with a twisting moment on it of 76,680 inch pounds, broke the next morning; the maximum twisting moment being 82,080 inch pounds. The shaft increased $\frac{1}{32}$ of an inch in diameter.

Rope Testing Machine. — A Manila rope, 4¼ inches in circumference, 100 inches long, and held by two eye splices, broke at the centre under a load of 15,000 pounds. The rope stretched 24 inches before breaking.

The other machines and appliances on exhibition were as follows: —

The 150 horse-power triple expansion engine.

The 16 horse-power Harris-Corliss engine.

A rotary pump, a plunger pump, and a pulsometer.

In the department of hydraulics was seen the discharge through a circular orifice 1 inch in diameter in a thin plate.

The Blake duplex pump, having a steam cylinder 16 inches in diameter, a water cylinder, 10½ inches in diameter and 12-inch stroke, discharged water through three nozzles over a weir four feet wide.

The following paper was read by title: —

New Genera and Species of Laboulbeniaceæ, with a Synopsis of the Known Species. By Roland Thaxter.

Eight hundred and sixty-third Meeting.

January 10, 1894. — STATED MEETING

The VICE-PRESIDENT in the chair.

The chair announced the death of Francis Parkman and Henry Warren Paine, Resident Fellows, and of Charles Merivale, Foreign Honorary Member.

The Corresponding Secretary read letters from W. K. Brooks, acknowledging his election as Associate Fellow; from E. Bornet, acknowledging his election as Foreign Honorary Member; and from the Corresponding Secretary of the Colonial Society of Massachusetts, thanking the Academy for affording the use of its Hall for the Society's meetings during the present season.

Barrett Wendell, on behalf of the Committee on Methods of Electing Officers, submitted a report.

On the motion of W. R. Livermore, it was

Voted, That this report be laid on the table.

The chairman of the Rumford Committee presented a report, and, in accordance with a recommendation contained therein, it was

Voted, To appropriate five hundred dollars from the income of the Rumford Fund to William H. Pickering for investigations on optical constants at different altitudes.

Granville Stanley Hall, of Worcester, was elected a Resident Fellow in Class III., Section 1.

C. L. Jackson read abstracts of the following papers: —

On the Formation of Volatile Compounds of Arsenic from Arsenical Wall Papers. By Charles R. Sanger.

Chronic Arsenical Poisoning from Wall Papers and Fabrics. By Charles R. Sanger.

Remarks on these papers were made by F. H. Storer, E. S. Wood, and W. G. Farlow.

The following papers were presented by title: —

On the Automorphic Linear Transformation of Bilinear Forms. By Henry Taber.

Contributions from the Gray Herbarium of Harvard University. By B. L. Robinson. I. Monograph of the North

American Alsineæ. II. New and hitherto imperfectly known Plants collected in Mexico by C. G. Pringle in 1892 and 1893. III. Notes upon the Genus Galinsoga.

On an Apparatus for the Measurement of Coefficients of Self-induction and the Investigation of the Phenomena of Alternating Currents. By Frank A. Laws. Presented by Charles R. Cross.

Eight hundred and sixty-fourth Meeting.

February 14, 1894. — MONTHLY MEETING.

The Academy met at the Walker Building of the Massachusetts Institute of Technology, Boston.

The PRESIDENT in the chair.

Elihu Thomson showed and described a number of phenomena produced by electrical discharges of high potential and of high frequency.

Work in this field began with Henry, and a considerable amount of experimentation in the same field has recently been carried on by Tesla, and others.

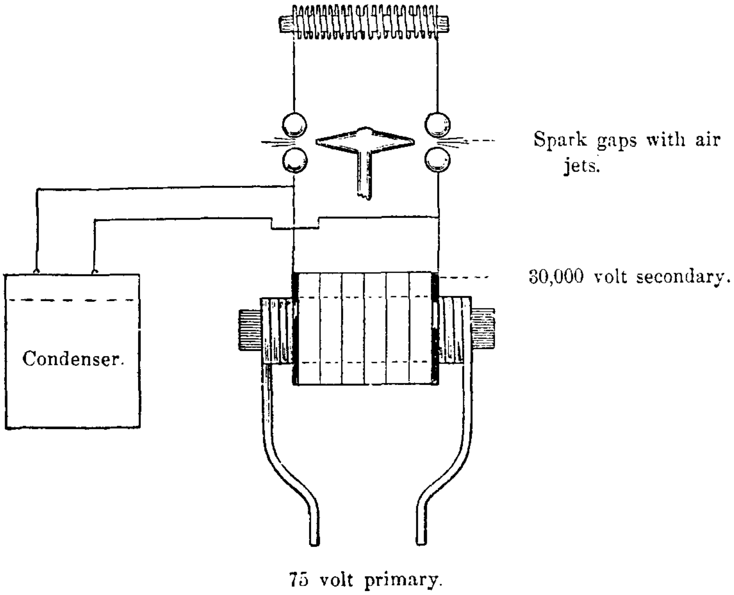
To obtain high frequency discharges, the current of an alternating current dynamo of 1,000 volts was reduced to 100 volts by suitable lighting transformers. This low pressure current was passed through the primary of a coil resembling a Ruhmkorff without break-piece, and raised to an alternating current of from 20,000 to 30,000 volts in the secondary, such current having still the original frequency of 120, that is 120 complete waves per second. This high pressure current was led directly into a large condenser, the metallic foils of which were insulated by a heavy mica sheet and contained in boxes filled with oil. The condenser, charged to 20,000 or 30,000 volts, in discharging jumped spaces or gaps between balls of brass through which spaces a strong air jet was kept blowing (Figure 1). The discharge circuit of the condenser includes these gaps, and may also include various coils, or plain wires, or paths designed to be traversed by the condenser discharge. If the condenser discharge takes place over a short path, of say only a few feet total length, the frequency or rate of alternation of the current composing the discharge may be several hundred thousand per second. This rate is so high that even a short length of conductor opposes the flow of current by its self-induction so greatly that lamps are lighted in a shunt to it, cards punctured, etc. (Figure 2). In fact, in one experiment an incandescent lamp was lighted in shunt to about 18 inches of $\frac{1}{4}$ inch copper rod, and the lamp was brought to full brilliancy (Figure 3). Moreover, it was distinctly shown that these currents are comparatively harmless, and may be passed through the body in an amount sufficient to light fully ordinary incandescent lamps (Figures 4 and 5); and the speaker stated that from the extremely small sensation experienced he thought it would be easily possible greatly to increase the current, and probably to an extent sufficient to light a small arc lamp.

The discharge circuit in this case had the form of a U of heavy copper rod, and it could be grasped so as to short-circuit it between points of such potential that insulation of considerable thickness would be readily pierced; but there was no disagreeable sensation, and very little sensation at all experienced.

The extraordinary energy of the induction of these discharges in the U-shaped conductor was shown by bringing near to it a rectangle of heavy copper wire the circuit of which was completed through a large incandescent lamp requiring more than one third of a horse-power of electrical energy to light it. It was found that the incandescent lamp could be brought far beyond its normal brilliancy on placing the rectangle a few inches away from the U (Figures 6 and 7).

By causing the condenser discharges to pass the air gaps and also a large open coil of about ten turns immersed in oil, the inductive effects of such coil on a parallel secondary coil having about 460 turns were exhibited. This secondary coil of 460 turns was wound on a hard rubber frame as a single layer, and the turns kept apart by a small space, and together with the primary immersed in a box or bath of oil of high insulating power (Figure 8). The ends of the finer and longer secondary were carried to the terminals rising out of the oil at the ends of the box or bath. and between these terminals torrents of sparks of about 30 inches in length were produced, accompanied by a loud roaring or crashing sound. Lateral discharges from the terminals were shown to be capable of being received through the body without injury, although of sufficient energy of current to light fully an incandescent lamp (Figure 9), and in fact to melt off the ends of fine wires, set fire to sticks of wood, etc. In this connection it was shown also that water was for these discharges a comparatively fair insulator, inasmuch as the sparks could be made to pass under water with substantially the same appearance as when they passed through air. Disruptive sparks as well as brush discharges were produced under water.

Fig. 1.
High frequency circuit.


Spark gaps with air jets.
30,000 volt secondary.
Condenser.
75 volt primary.

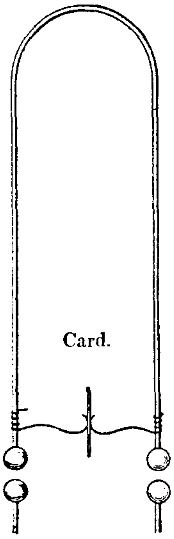


Fig. 2.
High frequency loop,
with shunt puncturing card.

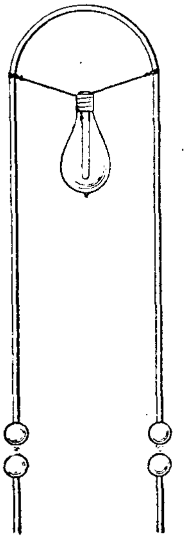
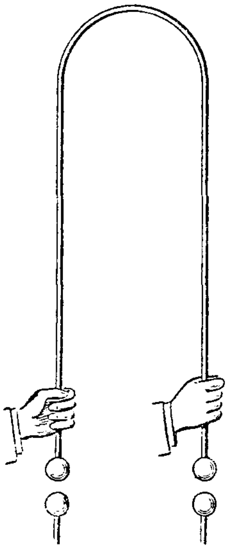


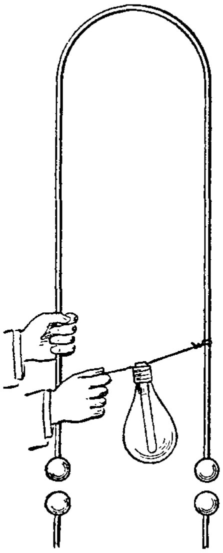
Fig. 3.
High frequency loop,
shunted by lamp.

Fig. 4.



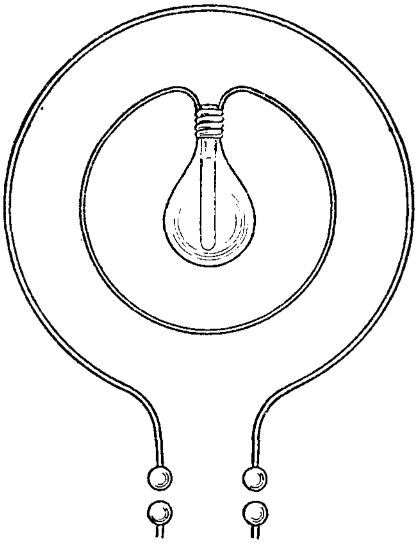
High frequency loop,
shunted by person.

Fig. 5.



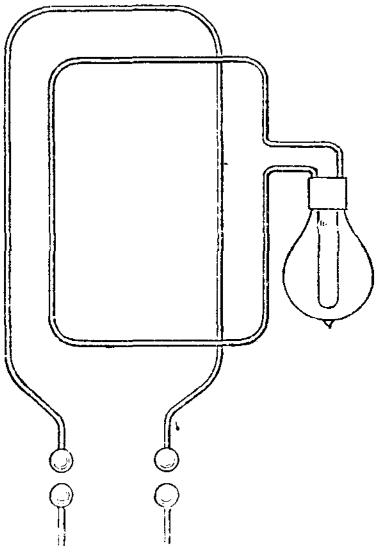
High frequency loop,
shunted by lamp and person.

Fig. 6.



High frequency round loop,
with circular turn and lamp lighted inductively.

Fig. 7.



High frequency loop, induction into adjacent circuit or loop, with large lamp between terminals thereof.

Fig. 8.

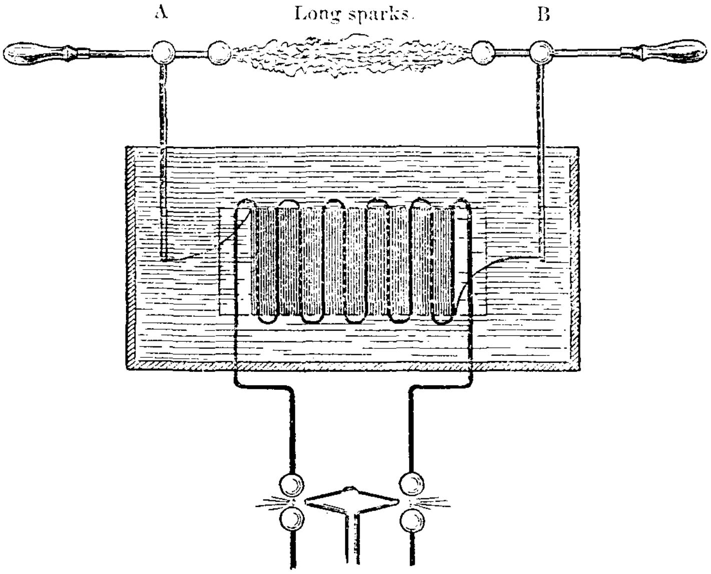
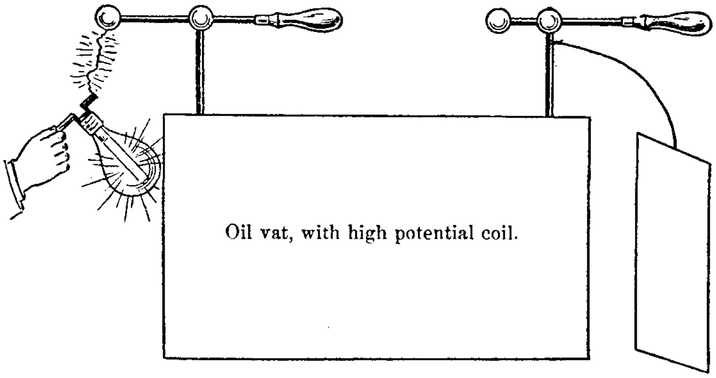


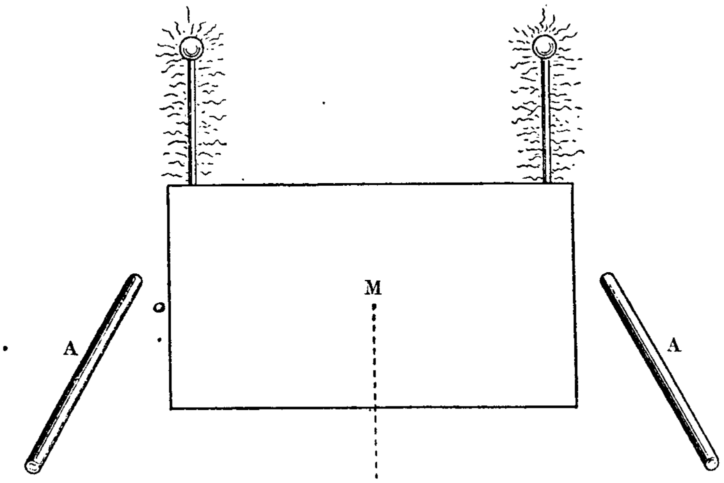
Diagram of vat with oil, immersed in which is the high frequency primary of few turns with secondary of a layer of finer wire of relatively 30 to 40 times the primary turns. Sparks obtained from prolongations of secondary outward or discharge terminals, A, B.

Fig. 9.


Oil vat, with high potential coil.

Lamp lighted by sparks from one terminal. Discharge traversing person's body.

Fig. 10.



Geissler tube, *a*, lighted by electrostatic field except at neutral position, *m*.

As exhibiting the electrostatic activity of the rapidly alternating electrostatic field around the apparatus, a long Geissler tube without metallic terminals was used, and brilliantly illuminated even at distances several feet away from the outside of the vat containing the induction apparatus. The tube, however, failed to light in one position; that is, in the centre plane dividing the apparatus into halves, which during action are electrified respectively positively and negatively at each alternation (Figure 10).

At the close of the experiments a vote of thanks was extended to the speaker.

S. H. Scudder exhibited a medal struck to celebrate the one hundredth anniversary of the birthday of Chevreul.

C. L. Jackson presented the following papers by title: —

On Mucophenoxychloric Acid. By H. E. Sawyer.

On Certain Bromine Derivatives of Resorcine. By C. L. Jackson and F. L. Dunlap.

The Smithville Meteoric Iron. By Oliver W. Huntington.

Eight hundred and sixty-fifth Meeting.

March 14, 1894. — STATED MEETING.

The PRESIDENT in the chair.

The chair announced the death of Pierre J. Van Beneden and of Sir James Fitzjames Stephen, Foreign Honorary Members.

The Corresponding Secretary read the following letters: from Edouard Van Beneden, announcing the death of his father, P. J. Van Beneden; from the Council of the Scientific Alliance of New York, calling attention to the proposed establishment of a fund for the endowment of research in honor of the late John Strong Newberry, and soliciting subscriptions thereto; from the Royal Academy of Physical and Mathematical Science of Naples, announcing a prize of 1,000 lire for the best memoir on prime numbers; also from the Executive Committee of the Eighth International Congress of Hygiene and Demography, and from the Tenth International Congress of Orientalists, inviting the Academy to take part in the work of those Congresses.

On the motion of C. S. Minot, it was

Voted, That the President be authorized to appoint delegates to either or both of these Congresses.

The following gentlemen were elected members of the Academy: —

Francis Mathews Green, of Boston, to be a Resident Fellow in Class I., Section 2.

Wallace Clement Sabine, of Cambridge, to be a Resident Fellow in Class I., Section 3.

John Donnell Smith, of Baltimore, to be an Associate Fellow in Class II., Section 2, in place of the late George Vasey.

The chairman of the C. M. Warren Committee presented a report, and, in accordance with a recommendation contained therein, it was

Voted, To appropriate from the income of the C. M. Warren Fund the sum of two hundred dollars ($200) to aid Charles F. Mabery, of Cleveland, Ohio, in making a systematic study of the petroleums of Ohio and Canada, with especial reference to the separation of the individual hydrocarbons therein contained.

On the motion of S. H. Scudder, it was

Voted, To take from the table the report of the Committee on Methods of Electing Officers.

A protracted discussion ensued, in which W. R. Livermore, A. Lowell, F. H. Storer, C. R. Cross, S. C. Chandler, C. S. Minot, H. W. Williams, S. H. Scudder, A. Hyatt, and G. Hay took part.

On the motion of A. Lowell, it was

Voted, That it be the duty of the Council annually to prepare a list of candidates for the offices of President, Vice-President, Corresponding Secretary, Recording Secretary, Treasurer, Librarian, Councillors, and members of the Standing Committees, and to cause this list to be sent by mail to all the Resident Fellows of the Academy three weeks before the Annual Meeting. Whenever the Council shall receive a nomination for any office, signed by not less than ten of the Resident Fellows of the Academy, it shall be the duty of the Council to publish such nomination with its own.

On the motion of the Corresponding Secretary, it was

Voted, To meet on adjournment on the second Wednesday in April.

The following paper was presented by title: —

On the Inheritance of Acquired Characters in Animals with a Complete Metamorphosis. By A. S. Packard.

Eight hundred and sixty-sixth Meeting.

April 11, 1894. — ADJOURNED STATED MEETING.

The Academy met at the Walker Building of the Massachusetts Institute of Technology, Boston.

The PRESIDENT in the chair.

The chair announced the death of Charles E. Brown-Séquard, of Paris, a Foreign Honorary Member.

On the motion of John Trowbridge, on behalf of the Rumford Committee, it was

Voted, To appropriate from the income of the Rumford Fund the sum of three hundred dollars ($300) to F. A. Laws in aid of his investigations on the thermal conductivity of metals.

Voted, To appropriate from the income of the Rumford Fund the sum of one thousand dollars ($1,000) to be expended in aid of investigations in light and heat. Payments from this sum to be made on the order of the Chairman of the Committee.

On motion of the Corresponding Secretary, it was

Voted, That the Committee of Publication be authorized to use for illustrations a portion of the regular annual appropriation for publications not exceeding fifty dollars ($50) for each paper. Larger appropriations of money from the general funds for illustrations to be made only by vote of the Academy at a stated meeting, on recommendation of the Committee of Publication, approved by the Treasurer.

The Corresponding Secretary gave notice of a proposed change in the statutes: to amend Chapter IV. of the Statutes by changing the numbers of Sections 4, 5, and 6, to 5, 6, and 7, respectively, and to insert a new section as follows: —

"4. The C. M. Warren Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications for appropriations from the income of the C. M. Warren Fund, and generally see to the due and proper execution of this trust."

On the motion of the Corresponding Secretary, it was

Voted, To refer this proposed change in the Statutes to a committee.

The President appointed the Recording Secretary as this committee.

On motion of the Librarian, it was

Voted, To present a copy of the Life and Works of Count Rumford, published by the American Academy, to the Rumford Kitchen.

The following papers were read by title: —

Further New and imperfectly known Plants collected in Mexico by C. G. Pringle in the Summer of 1893. By B. L. Robinson and J. M. Greenman.

On the Determination of Sulphur in Volatile Organic Compounds. By Charles F. Mabery.

Edward C. Pickering described the work in astronomical photography of the Harvard College Observatory.

Photographs were thrown upon the screen, some of which illustrated the following subjects: — The two principal stations of the Observatory at Cambridge and at Arequipa. Photographs of the double star ζ Ursæ Majoris, the planet Saturn showing its ring, and the occultation of a star by the Moon, taken by George P. Bond in 1857. Various members of the solar system, including Venus as a crescent, Vesta showing the method of discovering asteroids by photography, Jupiter, Saturn, Neptune and its satellite. Swift's comet of 1892. An eclipse of Jupiter's satellite. Eclipsed Moon, showing the method of searching for a lunar satellite. Photographs of the Moon taken at the Harvard station in Southern California, enlarging the image in the telescope; the results were compared with those obtained elsewhere. Great spiral Nebula in Orion, invisible to the eye, but covering a large part of that constellation. Method employed at Arequipa for making the 13-inch Boyden telescope follow the apparent motion of a star. Instead of a finder, images in the photographic telescope are used. The telescope is made to follow a star by means of an eyepiece outside of the photographic field. The entire plate is free to rotate around this eyepiece as an axis. The plate is then turned at intervals so that another star is kept in the axis of a second eyepiece. Sources of error, such as variations in flexure, in refraction, and in adjustment of the polar axis, which cannot be eliminated by the ordinary method with a finder, are thus corrected. Photographs of the clusters κ Crucis, ω Centauri, and 47 Tucanæ. Chart and spectrum plates of the vicinity of the variable star η Carinæ, showing stars of the fifth type and other objects having peculiar spectra. Distribution of stars of the fifth type. Identity of the spectra of α Aurigæ and the Sun. Spectrum of β Aurigæ, showing the lines single and double. Spectrum of a new variable star in Scorpius, showing the method of discovering variable stars of long period by means of the bright hydrogen lines in their spectra. Charts showing this star bright and faint. Light curve of this and of other variables. Spectrum plates showing the presence and absence of the new star in Norma. Charts showing the absence of this star before July, 1893, and its presence since then. Identity of the spectra of Nova Normæ and Nova Aurigæ. Spectra of Nova Aurigæ and o Ceti, showing the difference between the spectra of new stars and variable stars of long period. Method of detecting by inspection stars having a large parallax, proper motion, or variation in light; pairs of photographs are taken at intervals of six months, with the film side of the plate out and in; superposing plates taken six months apart in opposite positions so that the gelatine films are in contact, small deviations are perceptible; a motion corresponding to a parallax of $0''.6$ was thus readily visible across the room.

AMERICAN ACADEMY OF ARTS AND SCIENCES.

Report of the Council. — Presented May 9, 1894.

BIOGRAPHICAL NOTICES.

Moses Gerry Farmer	By Amos E. Dolbear.
Hermann August Hagen	Samuel Henshaw.
James Russell Lowell	Horace E. Scudder.
Henry Warren Paine	Nathaniel Holmes.
Francis Parkman	Barrett Wendell.
Henry Warren Torrey	William Everett.
Marquis de Caligny	William Watson.
Benjamin Jowett	William W. Goodwin.
Charles Merivale	Silas M. Macvane.

Notices of Wheatland, Van Beneden, Brown-Séquard, Marignac, and Stephen are necessarily deferred to the next volume; while those of Lowell and Caligny, deferred from last year, are given below.

REPORT OF THE COUNCIL.

SINCE the Annual Meeting of the 10th of May, 1893, the Academy has lost by death eleven members; — five Fellows, Moses Gerry Farmer, Hermann August Hagen, Henry Warren Paine, Francis Parkman, and Henry Warren Torrey; and six Foreign Honorary Members, Pierre Joseph Van Beneden, Charles Edward Brown-Séquard, Benjamin Jowett, Jean Charles Galinard de Marignac, Charles Merivale, and Sir James Fitz James Stephen.

RESIDENT FELLOWS.

MOSES GERRISH FARMER.

MOSES GERRISH FARMER was born in Boscawen, New Hampshire, in 1820. In his youth he had strong predilections towards scientific matters, and displayed some ability as a mathematician and as a musician, being able to play with skill upon the organ and some other instruments. In 1837 he was sent to Phillips Academy, where it seems he did as so many others having marked ability are reported to have done at school, namely, chosen to do something else than what was required of them, and here he was admonished that he was "disappointing the best hopes of his friends." He contrived, however, to enter Dartmouth College in 1840, but left before completing the college course. He began teaching at Elliot, Maine, and soon after had charge of the Belknap School in Dover, New Hampshire, where he remained until 1847. He became interested in electrical phenomena in 1845, and from that time on he devoted himself to enlarging the sphere of electrical industries, and in perfecting the apparatus employed. It is to be remembered that the first telegraphic line was built and operated in 1844, and on its success being demonstrated its development was very rapid, and Farmer became an operator and inspector in 1847, moving to South

Framingham, Massachusetts. He had already invented an electromagnetic engine and an electric locomotive, and had given numerous lectures on electrical subjects in the towns and cities about. It was at this time he devised the fire alarm system which was soon adopted by the city of Boston, he superintending its construction. This work has been ranked as the beginning of electrical engineering in the world. The automatic signalling apparatus, the control of powerful mechanical apparatus at a distance, the closed electrical circuits to be worked by interruptions, the adjustment of such circuits to a properly constructed battery, the devising of magneto-electric machines for producing powerful currents and driving such machines by water power, the protection of the conductors by placing them in pipes, the protection of the station itself from lightning by special ingenious apparatus, with many more things essential for the proper working and efficiency of the system, were devised by him, — for there were no such devices in existence and there was no experience. He was at work in an altogether new field, and his work was so well done that his system was adopted presently by all the cities in the country.

Mr. Farmer's work at Framingham required much Sabbath attention, and as he had conscientious scruples against such work he abandoned the position and moved to Salem in 1848. Here he devised several improvements in telegraphic apparatus, and became superintendent of the telegraphic line from Boston to Burlington, Vermont. Some of his inventions made within the next ten years have since been indispensable in doing telegraphic work. What is known as the automatic repeater is one with which he had succeeded before 1855 in sending four messages simultaneously over one wire, — what has since been called the quadruplex system. He invented too the first automatic printing telegraph, now known as the *ticker.*

In 1855 he succeeded in electrically depositing aluminum, and constructed for the Dudley Astronomical Observatory at Albany a chronograph and an electrical clock.

In 1856 he made an electric gyroscope so as to run continuously at uniform speed, and he read in that year a paper on Multiplex Telegraphy before the American Association for the Advancement of Science.

About this time he began investigations in the problem of electric lighting and advanced so far as to have his parlor in Salem lighted by an incandescent electric lamp in 1859. The supply of electricity was furnished by a galvanic battery, and he satisfied himself that with such a source of electricity electric lighting was not feasible.

From 1864 to 1868 he experimented much with thermo-electric devices, and discovered an alloy to be used for such a battery that had much higher efficiency than any others which had been employed, — one that compared favorably with the best we now have, except that it is rather too brittle for commercial use. With such a source, however, he coated steel and iron wire with copper for the sake of combining high conductivity with great tensile strength, and this was developed into a commercial enterprise of considerable magnitude. It was abandoned for some years, but its superior qualities for telephonic work have again made demand for it.

It appears that the first written description of what is now known as the self-exciting dynamo, in which the dynamo current is sent through its own field coils to strengthen its magnetism, was by Mr. Farmer in a letter to an eminent English electrician. The same idea occurred to several others about the same time, notably Siemens and Varley, but its immense importance did not so impress any of them as to put the idea into a practical form, and it remained for others unknown before in the electrical field to put it into the commercial shape so familiar now.

In 1872 he was appointed Professor of Electrical Science at the Torpedo Station at Newport, Rhode Island, a position which was quite to his taste, and where he remained for nine years.

During the first fifty years of his life he was in a constant struggle with poverty and sickness. Like Agassiz, he had no time to make money. He was so fertile in new things, he cared but little for the worth of his inventions; though he took out many patents, he profited little from them. His work was mostly of a fundamental sort, and few persons who have applied for patents on electrical devices for the past twenty years have not found that Farmer had preceded them in their territory, and there were few who had new ideas on any electrical matter who could not find in some of his numerous note-books the identical things already specified, and oftentimes the experimental work done, but not published, for he does not appear to have written much.

Mr. Farmer's relation to the electric lighting industry has not been generally known, but it appears that in 1868 he had a dynamo made with which he lighted forty incandescent electric lamps, in multiple arrangement, as is now the practice, and automatically regulated. His lamps were of iridium, which he found to possess the proper electrical qualities, but that metal not being found in an available form for commercial use, the system now so common was by him devised and carried out, lacking only the vacuum carbon lamp for completion. A fire in 1868 destroyed this first dynamo. The armature was the only portion that was rescued, and this was exhibited at the World's Fair in Chicago as part of an historic exhibit which he was preparing of his own work, when he was suddenly prostrated and died. For a number of years he had been unable to walk, owing to a paralytic attack, and it became impossible for him to do any work. Love for electrical science remained with him to the last, and it was a real pleasure to hear him tell of his attempts, his successes and his failures, though he was not one to introduce personal matters in conversation.

There is one event in his life which is worth chronicling, and which may not find its way into other notices. It may be remembered that a certain Dr. Gary, in 1878, had for a while on exhibition in Boston a machine which purported to be a perpetual motion. It was made with permanent magnets, and had a rotating armature so mounted as to change its polarity at certain points. Many saw this machine, but most thought there was some fraud about it. Professor Farmer went to see it, and asked permission to examine it, and was told he might take it to pieces and reconstruct it himself if he liked, which he did, and he told the writer the machine actually started up and ran without further attention. He offered to buy it, but the inventor did not want to sell. As Professor Farmer was an expert mechanician and electrician, it would seem unlikely that a piece of trickery should not have been discovered when subjected to such a critical examination in his own hands. To me it seems more likely that in some way there was a draught of energy for the propulsion from some source not hitherto recognized, able for a while to supply a small amount, for the machine would not run long at a time; but that it should run at all is the wonder, and Professor Farmer testifies that it did.

During the last years of his life he lived in Elliot, Maine, able to do but little on account of his paralysis. He could ride about somewhat and was an occasional visitor to Boston, but the younger race of electricians know of him only as a name. His work was chiefly done when electrical nomenclature had no existence, when there were no standards, when the whole field was new and telegraphy was growing, as the electric lighting industry has grown during the past ten years, and there was a great demand for electrical facilities for that kind of work. Mechanical aptitude was as much needed as an ally as it is now, and this combination of talents Professor Farmer possessed in a high degree.

1894. A. E. Dolbear.

HERMANN AUGUST HAGEN.

HERMANN AUGUST HAGEN was born at Königsberg, East Prussia, on May 30, 1817. His mother was Anna Dorothea Linck and his father Carl Heinrich Hagen, Professor of Political Economy, Technology, and Agriculture at the University of Königsberg. His education was obtained at the Gymnasium Collegium Friedericianum and at the Kneiphöfische Gymnasium; and after graduating from the latter in 1836 he studied medicine at the University of Königsberg.

Hagen's early interest in natural history, stimulated by his celebrated instructors, von Baer, Rathke, and von Siebold, was especially directed towards entomology by his father and his grandfather, the latter, Carl Gottfried Hagen, a Professor of Natural History in Königsberg and author of "Chloris Borussica," a small volume published in 1819.

It is said that the attention of young Hagen was called to the Odonata, or dragon-flies, "because by chance the first specimen he caught proved to be an undescribed insect of that order."

In 1839 in company with Professor Rathke he visited Norway, Sweden, and Denmark, and here, though he paid some attention to the habits and structure of marine animals, he studied chiefly in the principal entomological collections and libraries.

He received the degree of Doctor of Medicine from the University of Königsberg in 1840; his thesis being entitled "Synonymia Libellularum Europæarum," (Regimontii, 1840, 8°, pp. 84,) and indicating thus early the exactness which was so marked a feature of all his bibliographical work.

After his graduation in medicine, in 1840, Dr. Hagen studied in Berlin, Vienna, and Paris, and, returning to Königsberg in 1843, settled there as a practising physician and surgeon. At the surgical hospital, where for several years he was first assistant, he performed a large part of the operations; among the needy his services, always in demand, were given with that ready tenderness so characteristic of the sympathetic side of his nature.

His native city also claimed a large amount of his time during the years 1863–67, when as Vice-President of the City Council and a member of the School Board he was required to report upon a great number of subjects demanding much painstaking research.

Though educated as a physician, like so many of the older German men of science, Hagen, during all the years of his medical practice and of his civic duties, published continuously. His first entomological paper, a List of the Dragon-flies of East Prussia, was printed in the Preussische Provinzialblätter for January, 1839, when he was still at the University; * from that date until incapacitated in 1890 his contributions to science number several hundreds.

Some of these deserve special notice. In 1842, when studying in Paris, Dr. Hagen met Baron de Selys-Longchamps of Liége, and the friendship then begun resulted in the production through their joint studies of the well known "Revue des Odonates d'Europe" (1850), "Monographie des Caloptérygines" (1854), and "Monographie des Gomphines" (1857). The co-operation of De Selys and Hagen was not limited, however, to the works published conjointly; the writings of both had the advantage of a most generous interchange of notes, specimens, and drawings for a period of more than forty years.

The study of the insects found in amber and of the fossil Neuroptera early and continuously engaged his attention, his well known accuracy and thoroughness both in description and in delineation producing some of the best work yet done in palæo-entomology. The absence of generalizations, apparent in all his work, is conspicuous here; he was slow in framing hypotheses, ready and critical in testing their validity.

His "Monographie der Termiten," published in the Linnæa Entomologica for 1855, 1858, and 1860, is a masterpiece of original work, supplemented by a most exhaustive and thorough *résumé* of all previous studies in this most difficult of all families of insects; it will always remain a classic.

One of Dr. Hagen's earliest and most useful contributions to American entomology is the "Synopsis of North American Neuroptera," prepared at the special request of the Smithsonian Institution, and published by the Institution in 1861. With a keen insight into the systematic relations of forms, and quick to perceive specific differences, he possessed the rare power of stating these differences clearly and concisely.

Probably his best known work, certainly the one more frequently consulted by entomologists and zoölogists than any other, is the "Bibliotheca Entomologica: die Litteratur über das ganze Gebiet der Entomologie bis zum Jahre 1862," published in two volumes in 1862 and 1863. Modelled somewhat after the earlier work of Percheron, it is to day one of the most complete and accurately prepared of scientific bibliographies. The titles are arranged alphabetically under the names of the authors, and under each author's name in chronological sequence; entries are made under initials and pseudonyms when these alone are known, and anonymous works are arranged by subjects. An excellent and very detailed synoptic register affords easy reference, and adds greatly to the usefulness of the work. Like all his work, this was prepared with the most laborious painstaking; the libraries of Germany, France, Belgium, Holland, and England were examined, and an amount of drudgery that would have discouraged many was overcome by hard and persevering work.

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* Two earlier genealogical studies were printed in 1834.

From the study of various papers written by Dr. Th. Bail, Dr. Hagen became convinced that the ravages of various injurious insects could be readily checked by the application of the yeast fungus, and his paper on the "Destruction of Obnoxious Insects, Phylloxera, Potato Beetle, Cotton Worm, Colorado Grasshopper, and Greenhouse Pests, by the Application of the Yeast Fungus," (Cambridge, 1879,) though based on the mistaken assumption that the beer yeast fungus (*Saccharomyces cerevisiæ*) enters an insect's body and produces a disease, caused much discussion. Metschnikoff was thus led to examine several minute parasitic fungi, and was able to prove experimentally the deadly character of "green muscardine" (*Isaria destructor*) to insects exposed to infection. In his efforts to cultivate the "green muscardine" apart from the insects themselves, Metschnikoff used beer-mash successfully, producing thus a poison which once set at work multiplied and spread spontaneously, and it is probable that we have here the true explanation of the value of the application of yeast to plants affected by insects.

In 1867 Dr. Hagen left Königsberg and accepted the invitation of Professor Louis Agassiz to take charge of the entomological department of the Museum of Comparative Zoölogy at Cambridge; in 1870 as Professor of Entomology in Harvard College he commenced his University career. Dr. Hagen entered upon his duties at the Museum with great zeal; and his detailed plan for the arrangement of the collections, though somewhat modified, is, and is likely to remain, the basis for the future. Deeply interested in everything relating to museum work, as his appreciation of series of specimens, his care for their preservation and for the accuracy of their localities, and many minor details, clearly indicate, it is in this collection as well as in his writings that his contributions to science are to be found. Here alone we can fully realize the extent of his discoveries, the keenness of his insight, his skill at preparation and dissection and with the pencil. His devotion to the Museum knew no bounds; all personal interests were secondary. In 1876 he refused a most flattering and urgent invitation to take charge of the great entomological collections of the Königliches Museum für Naturkunde in Berlin, and the time that might have been given to original work was lavished upon the care and arrangement of the collections, which grew rapidly both in size and value. The biological collection, or that illustrating the life history of the species, is a prominent specialty of the Cambridge Museum. In this are preserved specimens showing every condition of an insect's life, the eggs, larvæ in all stages from those just hatched to those full grown, their burrows, nests. partially devoured leaves, etc., the work of both larvæ and adults, the frass or excrements often of great importance, pupal stages, adults of both sexes, and the parasitic and predaceous enemies also in all stages of development. Dr. Hagen's influence upon the formation of such biological collections has been very great; few were in existence at the time when, almost unaided, he created that at Cambridge, and the care and elaborateness with which the whole is labelled makes it not only a worthy model, but most truly a monument to persistent and well directed industry.

His lectures, given at rare intervals to advanced students, contained much genuine and exact knowledge, and his many acts of kindness and words of wise counsel will not soon be forgotten by those who enjoyed the facilities of the department under his charge.

Most of Dr. Hagen's journeys were undertaken for study among collections and in libraries. In the summer of 1882, however, accepting the generous and thoughtful invitation of Professor Raphael Pumpelly, at that time Director of the Northern Transcontinental Survey, he visited California, Oregon, Washington, and Montana. The object of the survey was to collect data concerning insects injurious to vegetation, both of the field and of the forest. The greater part of the time was spent in the Yakima and Columbia regions of Washington; many important entomological discoveries were made, some with a direct economic bearing, and large collections of insects were obtained from a most interesting locality. I had the good fortune to be one of the party accompanying Dr. Hagen on this occasion, and saw everywhere his delight at the great natural beauties of the country, and if the many discomforts, inseparable from such a trip to a man at the age of sixty-five, were borne with not a little impatience, yet his enthusiasm and determination assured his companions that the expedition would be carried to the end he had planned for it. In after years his experiences during the summer of 1882 were among the most enjoyable of his memories.

Dr. Hagen was a man of marked character, simple and sympathetic, and if at times somewhat hot and hasty in temper and impatient of opposition, he had also one of the warmest of hearts and most generous of dispositions. His unostentatious hospitality was enjoyed by many entomologists, who found his life in Cambridge quiet, contented, and happy.

Of Dr. Hagen's domestic life it is sufficient to record here that in 1851 he married Johanna Maria Elise Gerhards, who survives him.

Dr. Hagen received the honorary degree of Doctor of Philosophy from the University of Königsberg in 1863; Harvard made him a Doctor of Science in 1887. The renewal of his medical degree on the 17th of October, 1890, the date of his graduation fifty years previously, after the custom of German universities, gave him great pleasure. He was elected a Fellow of the American Academy of Arts and Sciences, November 11, 1868, and served on the Council in 1877–78. He was also a member of a goodly number of scientific associations, and most of the entomological societies the world over were glad to enroll him as an honorary member.

Stricken with paralysis in September, 1890, Dr. Hagen lingered for more than three years; his painful sufferings being lightened by all that affectionate and devoted care could do. He died at Cambridge, November 9, 1893, and was buried in the grounds of Harvard University at Mount Auburn, near his associate, Louis François de Pourtalès.

1894. SAMUEL HENSHAW.

JAMES RUSSELL LOWELL.

JAMES RUSSELL LOWELL was born at Elmwood, Cambridge, Massachusetts, February 22, 1819; he died at the same place, August 12, 1891. He was the youngest of a family of five, two daughters and three sons, born of Charles and Harriet Spence Lowell. His father at the time of Lowell's birth was thirty-seven years old and lived till 1861, when his son was forty-two. He was minister to the West Church, Boston, and his son has drawn his portrait in a letter to C. F. Briggs, written in 1844: "He is Dr. Primrose in the comparative degree, the very simplest and charmingest of sexagenarians, and not without a great deal of the truest magnanimity." The Lowells traced their descent from Percival Lowell of Bristol, England, who settled in Newbury, Massachusetts, in 1639, and in the generations just preceding that of James Russell Lowell three of the family besides his father had specially honorable names: Francis Cabot Lowell, who gave a great impetus to New England manufactures, from whom the city of Lowell took its name; Judge John Lowell, the author of the section in the Bill of Rights which wrote the death warrant of slavery in Massachusetts; and John Lowell, Jr., whose wise and far-sighted provision gave his native city that powerful centre of intellectual influence, the Lowell Institute.

Mrs. Harriet Spence Lowell, a native of Portsmouth, New Hampshire, was of Scotch origin. She is described as having "a great memory, an extraordinary aptitude for language, and a passionate fondness for ancient songs and ballads." It pleased her to fancy herself descended from the hero of one of the most famous ballads, Sir Patrick Spens, and at any rate she made a genuine link in the Poetic Succession. In a letter to his mother, written in 1837, Lowell says: "I am engaged in several poetical effusions, one of which I have dedicated to you, who have always been the patron and encourager of my youthful muse."

Elmwood in the days of Lowell's boyhood was in a more distinctly rural neighborhood than now, but it never has wholly lost its charm of seclusion. In his paper, "My Garden Acquaintance," in many of his poems, such as "An Indian Summer Reverie," "To the Dandelion," "Under the Willows," "Al Fresco," and in many passages in his letters, he bears witness to the intimacy which he enjoyed with that phase of nature which we may call homely and friendly. He once expressed to me his delight in Poussin's landscapes, and in his descriptive poetry it is noticeable that the large, solemn, or expansive scenes of nature make no such appeal to his interest as those nearer vistas which come close to human life and connect themselves with the familiar experience of home-keeping wits.

Lowell's school days were spent in his own neighborhood. Mr. William Wells, an Englishman and unsuccessful publisher, opened a classical school in one of the spacious Tory Row houses near Elmwood, and, bringing with him English public school thoroughness and severity, gave the boy a drilling in Latin which his quick appropriation of strong influences turned into a familiar possession. Possibly the heavy hand of the schoolmaster, by its repression, gave greater buoyancy to the spirit of the student when the comparative freedom of college followed. Lowell was sixteen when he entered Harvard College with the class which graduated in 1838. In "An Indian Summer Reverie," he says:

"Though lightly prized the ribboned parchments three,
Yet *collegisse juvat*, I am glad
That here what colleging was mine I had, —
It linked another tie, dear native town, with thee!"

Whether or no there was a reaction from the discipline of school days, it is certain that the independence which characterized Lowell throughout his life found expression now, not in insubordination, but in a frank pursuit of those courses of study and lines of reading which four years of academic leisure and the tolerable equipment of the college and home library put in his power. "Never," says Lowell in his essay, "A Great Public Character," when speaking of college life, — "Never were we ourselves so capable of the various great things we have never done"; and however much he may have been generalizing for college youth, he recalled well his own spiritual experience; with an impulse which outwardly was wayward, he obeyed that law of his being which his growing consciousness of intellectual power disclosed to him. In his penetrating discrimination between talent and genius, he says profoundly: "The man of talents possesses them like so many tools, does his job with them, and there an end; but the man of genius is possessed by it, and it makes him into a book or a life according to its whim. Talent takes the existing moulds and makes its castings, better or worse, of richer or baser metal, according to knack and opportunity; but genius is always shaping new ones and runs the man in them, so that there is always that human feel in the results which give us a kindred thrill. *What* it will make, we can only conjecture, contented always with knowing the infinite balance of possibility against which it can draw at pleasure." His was a singularly self-centred nature, and he was always true to that large ideal which was his consciousness of greatness projected in history and literature; but there was a whimsical uncertainty in his mind as to the precise direction in which his genius would at any time take him.

It is interesting to observe this self-centred nature in its early struggle after equipoise. So far as outward activity was concerned, he took a degree in law, but confessed to an aversion from the practice, and for a while busied himself in a counting-room. His vacillation of mind regarding his vocation, his apparent fickleness of purpose, the conflict going on between his nature craving expression and the world with its imperious demands, the stirring within him of large designs, and the happy contentment in the pleasures of the day, all seek outlet in his natural yet uneasy letters. He was finding himself in these early days, as many another young man, and there are glimpses all through Lowell's letters of this restlessness, this subtle sense of one's self which in weaker natures hardens into a mordant self-consciousness. Now and then he turns upon himself in a sort of mingled pride and shame, as if at once aware of his power and angry that he has it not wholly at his beck. But for the most part one is aware of a nature singularly at one with life, and finding its greatest satisfaction in getting at the world through the reflection of the world in literature. No one would deny that Lowell was eminently a man of books, but it would be a wholly inadequate phrase which described him as a bookish man. That he was at home in a library his early letters show, but they show also how even then he read through his books into life, and interpreted history and literature by means of an innate spiritual faculty which was independent of intellectual authority. It is this criticism at first hand, this swift, direct penetration of the reality, which mark emphatically what I have characterized as Lowell's self-centred nature. He has told us that his brain required a long brooding time ere it could hatch anything. He was speaking of the matter of expression; but the phrase is a fit one for his habitual temper. The superficial charge of indolence could apply only to his apparent disregard of bustling activity. His nature was of the sort that knows the power of stillness, and though he upbraids himself in his letters for his unproductiveness at times, he had plainly the instinct which waits on opportunity. His faculty of observation was very strong, but it was no stronger than his power of assimilation; and thus it was that when opportunity came he had not hurriedly to adjust himself to the situation.

It was while he was engaged with his books and his friends, professing law but practising literature in the way of poetical and prose contributions to the magazines, that he was roused out of his dreams by the prick of necessity in the sudden loss by his father of much of his property, and by the impulse given to his own moral force by the coming into his life of Maria White. He became engaged to this lady in the fall of 1840, and the next twelve years of his life were profoundly affected by her influence. Herself a poet of delicate power, she brought an intelligent sympathy with his work; it was, however, her strong moral enthusiasm, her lofty conception of purity and justice, which kindled his spirit and gave force and direction to a character which was ready to respond and yet might otherwise have delayed active expression. They were not married until 1844, but they were not far apart in their homes, and during these years Lowell was making those early ventures in literature, and first raids upon political and moral evil, which foretold the direction of his later work, and gave some hint of its abundance.

In 1841 he collected the poems which he had written and sometimes contributed to periodicals into a volume entitled "A Year's Life," and inscribed in a veiled dedication to his future wife. In hopes of bettering his fortune, and in obedience to the instinct which most young men of letters have, he undertook with Robert Carter the publication of a literary journal, "The Pioneer," which died under their inexperienced hands in three numbers. He began also to turn his studies in dramatic and early poetic literature to account, and after printing a portion in Nathan Hale's "Miscellany" published, in 1844, "Conversations on some of the Old Poets." In the same year he again collected his poetic work into a volume of "Poems." The difference between the two volumes of poems, though separated by three years only, is marked. Few of the verses from "A Year's Life" are included in the poet's final collection of his writings, few are omitted from "Poems." One poem in the earlier volume, "Irené," is conspicuous as a poetic portrait of the figure of peace which had come into his somewhat turbulent spiritual life, but the volume as a whole is characterized by vague sentimentalism and restless beating of half-grown wings. Three years later, some of this same immaturity is discoverable, but with the poems which wander in somewhat unmeaning ways are those spirited adventures like "Rhœcus," "The Shepherd of King Admetus," and "Prometheus," which denote the growing consciousness of positive poetic power, and also those stirring Sonnets to Wendell Phillips and J. R. Giddings, and the lines entitled "A Glance behind the Curtain," which disclose a new passion leaping up as the champion of truth and righteousness. It is noticeable, too, that in the first volume there is no trace of humor and scarcely any singular felicity of phrase; in the second, wit and humor begin to play a little on the surface. In "Conversations," where the familiar form gives freer scope, there is a gayety of speech which intimates the spontaneity of the man and anticipates the rich fruitage of later years. In all these books, however, there is good evidence of the rapid growth which was taking place in Lowell's intellectual and moral life, a coming to his own which it would take only some strong occasion to make sure.

This occasion was the Mexican War, with the greater contest which flamed up with it over the encroachments of slavery. Lowell and his wife, who brought a fervid antislavery temper as part of her marriage portion, were both contributors to the "Liberty Bell," and Lowell was a frequent contributor to the "Antislavery Standard," and was indeed for a while a corresponding editor; but in June, 1846, there appeared one day in the Boston Courier a letter from Mr. Ezekiel Biglow of Jalaam to the Hon. Joseph T. Buckingham, editor of the Boston Courier, enclosing a poem of his son, Mr. Hosea Biglow. It was no new thing to seek to arrest the public attention with the vernacular applied to public affairs. Major Jack Downing and Sam Slick had been notable examples, and they had many imitators; but the reader who laughed over the racy narrative of the unlettered Ezekiel, and then took up Hosea's poem and caught the gust of Yankee wrath and humor blown fresh in his face, knew that he was in with the appearance of something new in American literature. A score of years afterward, when introducing the Second Series of "The Biglow Papers," Lowell confessed that when he wrote this letter and poem he had no definite plan, and no intention of ever writing another. It was struck out from him by the revolt of his nature at the iniquity of slavery and the war into which slavery was dragging the nation. But he adds, "The success of my experiment soon began not only to astonish me, but to make me feel the responsibility of knowing that I held in my hand a weapon, instead of the mere fencing stick I had supposed. . . . If I put on the cap and bells, and made myself one of the court fools of King Demos, it was less to make his Majesty laugh than to win a passage to his royal ears for certain serious things which I had deeply at heart."

"The Biglow Papers" not only gave Lowell to himself and opened the flood gates of his patriotism and his noble indignation; they gave him a public, and thus furnished the complement which every author demands. "Very far," he says, in the same Introduction, "from being a popular author under my own name, so far, indeed, as to be almost unread, I found the verses of my pseudonym copied everywhere; I saw them pinned up in workshops; I heard them quoted and their authorship debated." The force which he displayed in these satires made his book at once a powerful ally of a sentiment which heretofore had been ridiculed; it turned the tables and put Anti-slavery, which had been fighting sturdily on foot with pikes, into the saddle, and gave it a flashing sabre. For Lowell himself it won an accolade from King Demos. He rose up a knight, and thenceforth possessed a freedom which was a freedom of nature, not a simple badge of service in a single cause. His patriotism and moral fervor found other vents in later life, and he never laid down the sword which he then took up, but it is significant of the stability of his genius that he was not misled by the sudden distinction which came to him into a limitation of his powers. It was shortly after this that he wrote, in one of those poetic absences from his every-day life, which were to overtake him more than once afterward, his "Vision of Sir Launfal," and the exuberance of his nature together with his keen power of criticism found expression about the same time in his witty "Fable for Critics." A third volume of Poems appeared in the same year, 1848, as the last named.

A year in Europe, 1851–52, with his wife, whose health was then precarious, stimulated his scholarly interests, and gave substance to his study of Dante and Italian literature. In October, 1853, his wife died, and in 1855 he was chosen successor to Mr. Longfellow as Smith Professor of the French and Spanish Languages and Literatures, and Professor of Belles Lettres in Harvard College. He spent two years in Europe in further preparation for the duties of his office, and in 1857 was again established in Cambridge and installed in his academic chair. He married also at this time his second wife, Miss Frances Dunlap, of Portland, Maine.

Lowell was now in his thirty-ninth year. As a scholar, in his professional work, he had acquired a versatile knowledge of the Romance languages and was an adept in old French and Provençal poetry; he had given a course of twelve lectures on English Poetry before the Lowell Institute in Boston which had made a strong impression on the community, and his work on the series of British Poets in connection with Professor Child, especially his biographical sketch of Keats, had been recognized as of a high order. In poetry he had published the volumes already mentioned. In general literature he had printed in magazines the papers which he afterward collected into his volume "Fireside Travels." It was not long after he entered on his college duties that "The Atlantic Monthly" was started, and the editorship given to him. For the details of the office he had little aptitude, although he looked keenly after nice points of literary finish in the proof-reading; he was relieved of much of the detail by his active assistant, Mr. F. H. Underwood, to whom the inception of the magazine was largely due. But the Atlantic afforded a good outlet for his literary production, and though he held the editorship but a little more than two years he stamped the magazine with the impress of his high ideals in literature and criticism; his selection of articles was judicious, his own contributions and criticism were full of life, and he was most generous in his critical aid to contributors. In 1862 he was associated with Mr. Charles Eliot Norton in the conduct of "The North American Review," and continued in this charge for ten years. In 1877 he was appointed by President Hayes Minister to the Court of Spain.

These twenty years, from 1857 to 1877 were the most productive period of Lowell's literary activity. He was in the maturity of his mental power, he held a convenient position in University life, his home relations were congenial and stimulating, and his collegiate work as well as his editorial charge successively of the Atlantic and North American gave him a needed impulse to literary effort. During this period appeared the most of that body of literary history and criticism which marks him as the most distinguished of American critics. Brought together in his writings under the general head of "Literary Essays," these papers are the rich deposit of a mind at once sympathetic and discriminating, capable of enjoying to the full the varied manifestations of life in literature, and yet an intuitive judge and penetrating critic.

While this broad stream of literary criticism was flowing, there was another expression of Lowell's nature, never divorced from this love of letters, — a criticism of life, especially as it took form in contemporaneous American history. The period which I have named covered the preparation for the war for the Union, that war itself, and the reconstruction era afterward, and the expression of Lowell's nature in its attitude toward the whole period was manifold. The volume of "Political Essays" contains the incisive papers which stung the irresolute and time-serving, and inspirited the ardent lovers of truth and liberty. It is impossible to read these papers now without admiration for the political sagacity of the writer, — a sagacity before the event, not after. Every page bears witness to the sanity with which he regarded contemporaneous affairs, when madness seemed the most natural temper in the world, and his insight of human nature was that of a poet who did not regard his power of vision as excluding the necessity of paying taxes. History has been supplying footnotes to these pages, with the result, not of correcting the text, but of confirming it.

In this same period also he wrote and published the Second Series of the Biglow Papers, and used his satire and his moral indignation with a depth of feeling which surpassed that shown in the first series, a little to the detriment thereby, it may be, of the brilliancy of the general effect. In truth, strong as was Lowell's power of invective, his passion of patriotism found this vent too narrow; there was a large, constructive imagination at work on the great theme of national life, which found fuller expression in the Odes which the Centennial and Commemorative occasions called out. Lowell seized the occasions with a spirit which scarcely needed them, and merely employed them as fit opportunities for casting in large moulds the great thoughts and feelings which rose out of the life of a man conscious of his inheritance in a noble patrimony.

It was at the close of this period, in which he had done incalculable service to the Republic, that Lowell was called on to represent the country, first at Madrid and afterward at London. Eight years were thus spent by him in the foreign service of the country. His sole participation in practical politics, as the term is, up to this time had been to attend a national convention once as delegate, and to have his name used as Presidential Elector. To the minds of many of his countrymen he seemed doubtless a dilettante in politics. Special preparation in diplomacy he had not, but he had what was more fundamental, a large nature enriched by a familiar intercourse with great minds, and so sane, so sound in its judgment, that whether he was engaged in determining a reading in an Elizabethan dramatist or in deciding to which country an Irish colossus belonged, he was bringing his whole nature to the bench. No one can read Lowell's despatches from Madrid and London without being struck by his sagacity, his readiness in emergencies, his interest in and quick perception of the political situation in the country where he was resident, and his unerring knowledge as a man of the world. Nor could Lowell lay aside in his official communications the art and the wit which were native to him. "I asked Lord Lyons," he writes in one letter, "whether he did not think suzerainty might be defined as 'leaving to a man the privilege of carrying the saddle and bridle after you have stolen his horse.' He assented."

But though Lowell's studies and experience had given him a preparation for dealing with diplomatic questions, the firmness with which he held his political faith afforded as sure a preparation for that more significant embassy which he bore from the American people to the English. Not long after his return, he published a little volume containing the more important speeches which he had made while in England. Most of them had to do with literature, but the title address in the volume, "Democracy," was an epigrammatic confession of political faith as hopeful as it was wise and keen. A few years later he gave another address to his own countrymen on "The Place of the Independent in Politics." It was a noble *apologia*, not without a trace of discouragement at the apparently sluggish movement of the recent years, but with that faith in the substance of his countrymen which gave him the right to use words of honest scorn and warning. What impresses one especially in reading this address, remembering the thoughtless gibes which had been flung at this patriot, is the perfect self-respect with which he defines his position, the entire absence of petty retaliation upon his aspersers, the kindliness of nature, the charity, in a word, which is the finest outcome of a strong political faith. It must have been galling to Lowell to find himself taunted with being un-American. He could afford to meet such a charge with silence, but he answered it with something better than silence when he reprinted in a volume his scattered political essays.

The public life of Mr. Lowell made him more of a figure before the world. He received honors from societies and universities; he was decorated by the highest honors which Harvard could pay officially, and Oxford and Cambridge, St. Andrews and Edinburgh, and Bologna, gave gowns. He established warm personal relations with Englishmen, and after his release from public office he made several visits to England. There, too, was buried his wife, who died in 1885. But the closing years of his life in his own country, though touched with domestic loneliness and diminished by growing physical infirmities that predicted his death, were rich also with the continued expression of his large personality. He delivered the public address in commemoration of the 250th anniversary of the founding of Harvard University, he gave a course of lectures on the Old English Dramatists before the Lowell Institute, he collected a volume of his poems, he spoke and wrote on public affairs, and the year before his death revised, rearranged, and carefully edited a definitive series of his writings in ten volumes.

1894. HORACE E. SCUDDER.

HENRY WARREN PAINE.

THE death of HENRY WARREN PAINE, LL.D., took place at his residence in Cambridge on the 26th of December, 1893. He had been a Resident Fellow of the American Academy in Class III. Section 1, Philosophy and Jurisprudence, from the year 1871. A membership so long continued may bear witness to the interest taken by our late associate in the advancement of knowledge and liberal culture beyond the immediate sphere of his own active life and achievements in the special field of the practical jurist.

He was born at Winslow in the State of Maine, August 30, 1810, a son of Lemuel and Jane Thomson (Warren) Paine. His father was a lawyer by profession, and in later years engaged in literary pursuits. His mother was a niece of General Joseph Warren, of Bunker Hill memory. His early education was well cared for, and he made rapid progress in his studies, taking little hand in the ordinary sports of youth. When duly fitted, he entered the College (now Colby University) at Waterville, Maine, in 1826, and graduated with the highest honors in the Class of 1830. In his Senior year he was also Principal of the Waterville Academy, and served one year as Tutor in the College. He then began the study of law in the office of his uncle, Samuel S. Warren, and continued it with William Clark, of Hallowell, and then for one year in the Law School of Harvard University, and was admitted to the Bar in Maine in 1834.

In the course of twenty years of practice at Hallowell, Mr. Paine had attained a distinguished position in the profession, had been for five years Attorney for Kennebec County, and had served for several years (between 1836 and 1853) as a Representative of Hallowell in the State Legislature. Tempting offers of further political promotion, and even a seat upon the Supreme Bench of the State, were declined. It seems to have been his purpose to adhere strictly to the line of the profession he had chosen. Chief Justice Appleton spoke of him as "a profound and learned lawyer, as well as an accomplished advocate." It is evident that by the year 1853 he had determined to seek a wider field for his exertions in the metropolis of New England. Mason, Webster, Fletcher, Choate, and many others, had done the like before him. These were indeed perilous examples to be followed, unless a man felt quite sure of his own strength. Perhaps he had heard of the remark of Mr. Webster, that "there was always room enough up above." In 1854 he had removed his office to Boston, and established his residence in Cambridge. Not long afterwards he was engaged with Rufus Choate and F. O. J. Smith in the impeachment trial of Judge Woodbury Davis at Portland, on which occasion it was remarked that "Paine furnished the logic, Choate the rhetoric, and Smith the slang."

For the rest of his life Mr. Paine steadily pursued his professional avocations in Boston, where he soon acquired both a large business and a high standing at the Bar. It is said that his charges were always moderate. With a practice sufficiently lucrative for all his needs, he showed no grasping eagerness for excessive wealth. Indeed, a great lawyer is apt to think that, if a man desires to be very rich, he should quit the law and go into the oil business. For many years, almost the only relief he could find, or could allow himself, from pressing employments and assiduous labors, was in the quiet enjoyment of his elegant home, with his books and private studies, or in social intercourse with his friends. Those who knew him best speak highly of his social qualities, his kindness of heart, his agreeable conversation, and the conservative character of his views in general. In public affairs, while he was a firm supporter of constitutional government and law, his sympathies leaned to the side of the Democratic policy; in religion his affiliations were with the liberal Unitarian Church.

The proceedings of the Bar meetings in Boston upon occasion of his death may furnish the best evidence of the high estimation in which the character and professional career of Henry W. Paine were held by his brethren of the bench and bar. They signalize his eminent ability as a lawyer and advocate, his learning in the law, his literary attainments, his wit, uniform courtesy of manner, and constant regard for the honor and dignity of the profession; and they further assure us that his sterling integrity and skill were so generally appreciated by the community at large as to reflect credit on the calling, and tended to strengthen the confidence of the public in the faithful administration of justice in the courts. It is said that the place of Chief Justice of this State was on one occasion tendered to Mr. Paine, an honor which he felt constrained to decline, for reasons doubtless satisfactory to himself. No one could be more fully aware of the exhausting labors and weighty responsibilities of high judicial station. Mr. Justice Nelson once observed that, what with hearings and consultations by day and the writing of opinions in the night, the best if not the only time he could have, he had often wished he had been some plain farmer, who could sleep soundly when his day's work was done.

In 1854 the degree of LL. D. was conferred upon Mr. Paine by Colby University, of which he was a Trustee. He was also a member of the "Historical Society" in Maine. From 1870 to 1882 he served as one of the Board of Overseers of Harvard University; and from 1872 to 1883 he was a Lecturer on the Law of Real Property in the Law School of the Boston University, and such were his powers of mind and memory, and such his knowledge of the subject, that he was able to deliver his lectures orally, and to the entire satisfaction of his hearers, upon this abstruse and difficult branch of the law.

In later years, when a slight deafness began to interfere with his appearance in court, his office practice was rather increased than interrupted. Many cases of importance were brought before him as referee, or Master in Chancery, and his opinions and advice were much valued and often sought. At the age of about seventy-five his memory began to fail, but still, when once reminded of the lost facts, he would discourse as intelligently as ever upon the topic in hand; and he sometimes remarked that he had been all his life a close student, had never hunted, fished, or swum, had never drunk, snuffed, smoked, or chewed, and had been so continuously occupied with his life-work, to the neglect of needful rest and recreation, that he feared he was now to suffer the penalty of an over-tasked brain. His daily visits to his office were continued almost to the last, and he read his newspaper as usual but a day or two before his death at the quite venerable age of eighty-three.

In 1837 Mr. Paine married Miss Lucy E. Coffin of Newburyport, Massachusetts, who is said to have been a lady of rare accomplishments, and was in after life worthily active in charities and good works. She died on March 16, 1887. They left an only daughter, Miss J. W. Paine, of 66 Sparks Street, Cambridge.

In the "Bay State Monthly" for November, 1885, may be found an appreciative sketch of the life of Henry W. Paine, with an excellent portrait, written by his early pupil and life-long friend, Professor William Mathews, LL. D.

1894. NATHANIEL HOLMES.

FRANCIS PARKMAN.

I.

FRANCIS PARKMAN was born in Boston, on the 16th of September, 1823. The son of the Reverend Dr. Francis Parkman, an eminent Unitarian minister, and of Catharine, daughter of Nathaniel Hall, of Medford, he belonged by birth and tradition to the gentry of New England, whose right to a certain consideration and dignity was in those days still recognized. "His childhood," to use his own words, "was neither healthful nor buoyant. His boyhood, though for a time active, was not robust, and at the age of eleven or twelve he conceived a vehement liking for pursuits a devotion to which at that time of life far oftener indicates a bodily defect than a mental superiority." The chief pursuit in question was chemistry, in which he dabbled with no good result. At fifteen or sixteen, however, his tastes took a new turn and this time a permanent. "He became enamored of the woods, — a fancy which soon gained full control over the course of the literary pursuits to which he was also addicted." In 1840 he entered Harvard College. Here, he writes, "before the end of the Sophomore year my various schemes had crystallized into a plan of writing the story of what was then known as the 'Old French War,' — that is, the war that ended in the conquest of Canada, — for here, as it seemed to me, the forest drama was more stirring and the forest stage more thronged with appropriate actors than in any other passage of our history." — This was about 1842. — "It was not till some years later," he goes on, "that I enlarged the plan to include the whole course of the American conflict between France and England, or, in other words, the history of the American forest; for this was the light in which I regarded it. My theme fascinated me, and I was haunted with wilderness images day and night."

The purpose thus conceived he always adhered to. In carrying it out, however, he met and surmounted obstacles that to almost any other man would have been fatal. In the Proceedings of the Massachusetts Historical Society for November, 1893,* is printed the characteristically impersonal autobiographic fragment from which my quotations are taken. Written with no purpose of confession, but rather as a pathological document of possible value to the future, it may best not be quoted in detail; it is accessible to whoever cares to read. With the calmness of a scientific narrative, it tells the story of an obscure, almost unique malady — physical, mental, nervous, by turns — which pursued him from early youth to the end. Among the first specific symptoms was a weakness of sight, which persisted throughout life, and which rapidly grew so serious that, years afterwards, he notes with satisfaction that he can at length permit himself to read, on the average, five minutes at one time. At intervals, one of which extended through four years, he found himself unable to bear the slightest mental concentration. Another trouble was a difficulty of the knees, which occasionally crippled him; and his temperament was remarkable for physical activity. In the earlier stages of his trouble he had striven to conquer it by physical exercise. This resulted in a muscular power which even his prolonged illness never destroyed. An athletic boy, who knew him in his sixty-ninth year, lately expressed an admiring hope that he might some day grow strong enough to pull a boat like Mr. Parkman. With a moral strength only shadowed by this lasting strength of muscle, he adhered to his youthful purpose through this whole lifetime of suffering.

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* Mass. Hist. Soc. Proceedings, Second Series, Vol. VIII. pp. 350–360.

During his college course he had to go abroad for his health. He returned in time to take his degree in 1844. For a little while he studied law. Then, his eyes failing him, he started, in search of health and of material for his history alike, on that exhausting journey to the then savage West, which he has recorded in "The Oregon Trail." The physical strain served only, in the end, to confirm his trouble. The book in which he tells the story was dictated, chiefly from memory, to the kinsman who was his comrade on the journey. It was published in 1847.

In 1850 he was married to Catharine Scollay, daughter of Dr. Jacob Bigelow, of Boston. In 1851 appeared the first fruit of the historical purpose which he had already cherished for nine years. In this book — "The Conspiracy of Pontiac" — is virtually sketched the whole plan of the historical work which occupied him for forty years to come. A few years later he published a novel, "Vassall Morton," which he is said subsequently to have regretted. It was produced at moments when his health forbade him to work seriously at the task he really cared for. In parts, perhaps, it was more nearly autobiographic than he meant it to be. A cheerful reticence about himself was one of his marked traits. "Vassall Morton," they say, he disliked to hear mentioned; it has generally been forgotten. Another of his avocations, however, will always be remembered. In 1851 he bought a small place on the edge of Jamaica Pond, where he lived, for part of the year at least, until his death. Here, as his strength permitted, he devoted himself to horticulture, with such results that his name is almost as familiar to lovers of flowers as to lovers of books. It was here that he died. The garden he so cared for has already become a part of the great park system of Boston.

In 1858 Mrs. Parkman died, leaving two daughters. In the same year he went abroad for his health. It was not until 1865 that his next book appeared, — "The Pioneers of France in the New World." From this time his power of production increased. His malady, perhaps, was beginning to relax. In 1867 came "The Jesuits in North America," in 1869 "The Discovery of the Great West," in 1874 "The Old Régime in Canada," in 1877 "Frontenac," in 1884 "Montcalm and Wolfe," in 1892 his final book, "The Half-Century of Conflict." Though the conflict referred to in this title is of course that between France and England for the continent of America, the title, by a happy accident, has a peculiar felicity. Just half a century had elapsed since 1842, when he first conceived the historical plan which at length he had finished. On the 8th of November, 1893, he died, after a very short illness, at Jamaica Plain.

Remarkable as this mere statement of his achievement is, it by no means includes the whole story. The many journeys and researches demanded for the collection of his historical material might be inferred from the results of his historical work. He found time and energy also for much other activity. To name only a part of this, he was for thirteen years a Fellow of the Corporation of Harvard College, and for six years an Overseer; he was an active member and Vice-President of the Massachusetts Historical Society; for its first six years he was President of the St. Botolph Club; and he wrote not a few articles for newspapers and magazines, on matters of public import. In 1855, he became a Fellow of the American Academy. He was rarely, if ever, able to attend its meetings; but no name on its lists was more cordially honored.

II.

Mr. Parkman was the last and in many respects the ripest of the romantic historians who for more than half a century gave distinction to the literary life of New England. Younger than the others, surviving them all in spite of his prolonged years of illness, and doing his best work toward the end of his life, he seems to-day a far more modern figure than Prescott, or Ticknor, or Motley. More than theirs, too, his work concerned our own country. The chief centre of his interest, from the beginning, was the frontier of that British civilization in America from which has sprung the United States. From the first lines of "The Conspiracy of Pontiac," one may say, his work tended unerringly toward the closing words of "Montcalm and Wolfe": The United States "has tamed the savage continent, peopled the solitude, gathered wealth untold, waxed potent, imposing, redoubtable; and now it remains for her to prove, if she can, that the rule of the masses is consistent with the highest growth of the individual; that democracy can give the world a civilization as mature and pregnant, ideas as energetic and vitalizing, and types of manhood as lofty and strong, as any of the systems which it boasts to supplant."

This constantly national purpose, none the less profoundly patriotic that with the open sincerity which has always been the virtue most cherished by men of Harvard he disdained to neglect or to deny our errors and our dangers, makes his work peculiarly ours. The literary sensitiveness, too, with which his style changed from what now seems the somewhat excessive floridity, or at least the figurative formality, of half a century ago, to the direct, fluent simplicity of the best modern English, makes him above most men of letters steadily contemporary.

Besides this, his unswerving tenacity of purpose makes his work singularly complete. In the first six chapters of "The Conspiracy of Pontiac," as I have said, he sketched what may broadly be called the whole scheme of his historical writing. For forty years of enthusiastic study, in the course of which he sought out every available authority, he busied himself in finishing, on the grand scale, the picture thus sketched. In its own way, then, his work probably stands among the most permanent that has been done by American hands.

Perhaps its most salient trait is its unbroken vitality. His imagination was very vivid. To him men were always alive, — thinking, feeling, acting, stirring, in the midst of a living Nature. To him a document of whatever kind — a state paper, a Jesuit "Relation," the diary of a Provincial soldier, the record of a Yankee church — was merely the symbol of a fact which had once been as real as his own hardships among the Western Indians, or as the lifetime of physical suffering which never bent his will. In turning from "The Oregon Trail" — the single volume which records experience of his own — to the series of volumes which record the experience of men who have been dead for generations, one feels strangely little difference. Both alike are records of actual human existence.

This constant vitality is generally recognized. By those who know his work well, indeed, it is by and by assumed, in a mood akin to that in which the great generalizations of human wisdom are accepted by posterity as commonplace. If much remarked, it is spoken of as notable in view of the maladies which kept him so long a cripple or an invalid. These, it is said, in no way impaired his scholarly and artistic vigor. To a great extent, the remark is true. More vivid writing than his is hard to find; nothing could be further from what he called "the pallid and emasculate scholarship of which New England has already had too much."

For all this vitality, there is an aspect of his work which thorough criticism cannot neglect. Here and there one sometimes hears from people who cordially admire his writings an occasional expression of regret that he did not devote his exceptional powers to the execution of a task in itself more important. After all, these critics say, he has only told us — incomparably, to be sure — how European missionaries and pioneers penetrated and tamed the American wilderness, and how in the end the provinces that used to be French became subject to the Crown of England. Full of vigorous interest as all this is, it sometimes seems — in this age of grave constitutional and philosophic study — just a shade puerile. Boys like to read it. Nowadays this is often reason enough for grown people to think it a bit the less worth their attention.

In this criticism there is some apparent truth. Undoubtedly Mr. Parkman's first youthful purpose was, in his own words, to write "the history of the American forest," which incidentally should include the long struggle between France and England. Undoubtedly his love for the woods pervaded his fancy to the last. Undoubtedly, in comparison with much that has happened on earth, these matters seem at first glance rather picturesque than notable, of romantic interest rather than of historic. To assert that they are really so, however, is not to understand them. A little consideration reveals them in a different light. Historical phenomena of any kind must be the result of historical forces; and though here the historical phenomena may sometimes seem trivial, the historical forces that underlie them prove before long to be of prime importance. In the first place, we have European civilization inevitably, unwittingly overpowering the barbarism of savage America. In the second place, far nearer to ourselves, we have the absolutism of the old French monarchy struggling to the death for the dominion of a conquered continent with that firmest known system of human rights, — the common law of England. All this, too, we have implied in Mr. Parkman's own pages; to feel it so that we may philosophize about it to our hearts' content, we need only turn to him. The matters he deals with, then, are really matters grave enough for anybody.

The fact that the seriousness of his work is not to all readers instantly apparent, however, is in itself significant. Here, and only here, I think, is revealed the superficiality of that commonplace criticism which declares that his illness in no way affected his achievement. Whoever knew him, at least in his later years, must have felt that the man himself was as far removed as possible from that delightful but unimportant personage, the mere teller of stories. You could not talk with him for five minutes without feeling that he not only knew things, but thought about them too: that, to a rare degree, he was a critic of life. In his historical work, however, this trait, though by no means absent if one will but search for it, is not quite obvious. In his later books, to be sure, it is more apparent than in his earlier; implicitly, after a while, one finds it everywhere; but to find it one must sometimes search. To a superficial reader, in fact, the luxuriant profusion of his detail — a trait which would naturally result from the circumstances under which his illness compelled him to work — must sometimes obscure the principles which any one who knew him knows that he constantly realized to underlie the facts and the people he has made so vividly real. A deliberate practice of his, too, gives color to the superficial criticism. He was very sparing of generalization, of philosophic comment. For this he had good reason. To philosophize with certainty of conviction means to think long and hard; to philosophize flippantly means not to realize the responsibility which lies on whoever dares to leave written records behind him. This responsibility Mr. Parkman fully realized; from the beginning of his life to the end his infirmities forbade him sustained intensity of thought. To them, I believe, and only to them, we may attribute our misfortune in that this gentlest and ripest of our historical writers has not left us books that should instantly show him beyond question the gravest of our historical thinkers.

III.

Mr. Parkman's personality was so marked that any memory of it is worth recording. I shall ask no further justification for telling here what I remember of him.

Before I ever saw him, or ever read a line of his writing, I had heard, like any man of my age, a good deal about him. In the first place, he was one of the New England historians; and somehow these writers, I think, were generally held by the local public opinion of their time rather more profoundly respectable than anything else on earth. In the second place, though the actual details of his illness were not generally known until the publication of his autobiography, the fact of his illness was of course apparent. I have no earlier memory than of tales about him, very properly presented to my childish mind in the light of a good old-fashioned example. In spite of his illness, he had written his books, and was going to write more. In spite of his lameness, he was sometimes to be seen, walking with two canes, but still with a brisk step, resting at intervals for a fresh start. Mentally and physically, then, he was indomitable. The fruit of these anecdotes in my mind was that inarticulate sentiment of awful respect so familiar to the traditional youth of New England.

When I first saw him, I was still an undergraduate in Harvard College. The circumstances of this first sight vanished from my memory long ago. In this very fact there is something characteristic of the man; locally notable as he was, and notable too in personal appearance, he was very unobtrusive in address, and in general company he was little given to talk. All I can now recall of the beginning of the time when to me he changed from a personage to a personality is that, at certain intervals, I began to meet him here and there; that his strongly featured, smooth-shaven, thin face looked as if made for an expression of severity; and that there was always about his eyes and his mouth an expression of alert, kindly interest in whatever was doing, which did away with the notion of severity altogether. Remarkably self-contained, you felt him after a while; but, to a still more remarkable degree, not a bit self-centred. For all his firmness of aspect, and all the reputation by which this firmness was more than justified, you found yourself insensibly growing to think of him chiefly as a keenly interested observer. Alert, observing, kindly he looked, whether in a private house, or in the full dignity of the Commencement stage at Harvard, where he would sit with the other Fellows of the Corporation behind that impressive rail on the stage of Sanders Theatre, which in any less dissenting atmosphere would so inevitably remind one of an altar. Perhaps the most vivid memory I have of him in those days is of how he sat one Class Day evening in a doorway of Holworthy Hall. He had come to Class Day with one of his daughters; he did not wish to hurry her home. Very likely, he was pretty well tired out; but he did not look so. He sat there, in the dim light of the lanterns, listening to the singing of the Glee Club, leaning forward a little, resting one hand on his cane, talking very little, but just watching, with his kindly, half-amused look, the swarms of young people who were passing. Somehow the memory of his figure has clung ever since to that doorway of Holworthy. It was not a bit the figure of a grave, heroic historian; it was just that of a quiet, kindly New England gentleman.

Several years later I first chanced on the historian that was in him. Meanwhile I had grown to know him better, meeting him always with the pleasure that comes to one from a cordially friendly greeting, but never getting further. In the early autumn of 1880 he was abroad, collecting material, I believe, for his last books. One day I happened to meet him in the Luxembourg Gallery; and by mere chance to stop with him before Delaroche's familiar picture of the death of the Duc de Guise. My notion of the historical circumstance therein portrayed was deplorably vague. I happened to say so. Thereupon Mr. Parkman began to tell the story with the vividness so familiar in his writings. All the essential details of time and place were at his tongue's end, — picturesque little touches, too, of what this personage and that said or wrote. It was such a bit of story-telling as now and then you hear from an eyewitness, — just as vividly real as if he had lived at the court of Henri III. If it had lain in the direct course of his professional study, it would have been remarkable; lying, as it did, a little beyond his actual province of work, it was astonishing. You began to wonder whether, in that stirring imagination of his, he had stored away all the picturesque facts of recorded history. Very likely his accurate knowledge of the Guise times was a matter of chance. It was a chance, though, which happened to be very impressive, — all the more because of the extraordinary power of oral composition which had come to him from the frequent necessity of dictating rather than actually writing his books.

For several years after this, I have but two distinct memories of him, — one general, the other individual. The first is of his presidency of the St. Botolph Club in Boston. Founded early in 1880, for the purpose of bringing together men genuinely interested in literature and art, it contained in its earlier years many of the most interesting men in New England. Mr. Parkman was its first President. His health did not allow him often to attend the larger meetings of the club, which at that time occurred every Saturday evening. What one remembers, then, is the pleasant stir which would go through the room when now and then he would unexpectedly appear. He would generally sit on a sofa, leaning back perhaps a shade more languidly than one commonly remembers him. He would talk, with more animation than usual, to whoever chanced to be near at hand. He would greet whoever approached with a cheeriness which made one feel as if the pleasure of meeting were mutual. Here, as everywhere else, it was the man whose presence that you felt, and not the historian. Little by little you began to wonder whether the grave, heroic personage of your youthful tradition could possibly be identical with this alert, kindly, quietly sympathetic human being.

My other distinct memory of him, in these years, is perhaps too complacently personal for record. One afternoon in the first months of my married life, when I happened to be alone at home, his card was brought to me. A moment later he came up stairs to the little library where I was sitting. He did not stay long, he said very little. I was a bit conscious, I suppose, and I rather think there was a moment or two of conscious silence. The fact that he came in person, though, to wish God speed to a pair of young friends just beginning their married life seems to me worth remembering. Just that sort of friendly kindness is not so common in New England as to be commonplace.

It was only during the last two or three summers of his life that I saw him with anything approaching intimacy. In "The Half-Century of Conflict" he mentions that he wrote at least part of his story of Sir William Pepperell's conquest of Louisbourg in the old house that in Pepperell's day was the county seat of Benning Wentworth, Governor of New Hampshire. Then he goes on to write some pleasant descriptions of the country about the mouth of the Piscataqua. The old Wentworth house, some few years ago, passed into the possession of Mr. Parkman's son in law. Mr. Parkman found the region pleasant and restful. He slept there more soundly than elsewhere. So he would come and stay there for weeks at a time; and there as a neighbor, I saw him constantly.

The old house is a large, rambling structure, absolutely without the pseudo-classic dignity and proportion which distinguish most of the architecture of Colonial New England, and for that very reason it is perhaps the most romantic, unexpected mansion which has survived here from the time of George II. It lies rather low on a point of land which separates Little Harbor — the smaller of the two outlets of the Piscataqua — from a tidal creek that runs two or three miles inland, to lose itself in salt meadows. When the tide is low, creek and harbor alike are almost dry; but when the tide is high there is no better water anywhere for rowing and sailing; and the constant variety of aspect which comes from this daily contrast combines with the romantic air of the old house, half hidden by lilac bushes almost as old as itself, to give the region a charm peculiarly its own.

In this environment, so pleasantly fitting for the historian whose chief work dealt with the colonial times of whose memory the region is full, Mr. Parkman was seen oftenest, perhaps, in a character as remote as possible from the humdrum dignity of history. While he was rarely able to walk much, his arms and chest were generally in prime condition. On crutches, or at best with the help of a cane, he would come briskly down to the pier, where a small fleet of small boats was constantly lying; he would seat himself in a queer, nondescript little row-boat made to suit him by a local genius; and he would pull himself about for hours at a time, or perhaps anchor himself and fish contentedly, as long as the tide served, for small cod or perch. His personal appearance at these moments may be inferred from an incident that amused him one day. At some little distance from home he observed a fisherman hauling in lobster-pots, and rowing alongside to watch his luck, was much impressed by the man's stalwart honesty in carefully measuring every lobster with a foot rule, and throwing overboard all that were not indubitably of full legal size. After a friendly interview, the couple parted company. A few days later, Mr. Parkman discovered that the exceptional stalwartness of this fisherman's honesty was at least partly due to the fact that the man had mistaken him for an official inspector of the local fisheries.

When one met Mr. Parkman thus taking his ease, one grew aware of a certain boyish freshness of feeling and nature in him. If he caught sight of you on the shore, or in a passing boat, he would wave his hand with a jolly sort of greeting, or perhaps, if you were near enough, would shout a friendly word or two. As I have said before, too, the vigor with which he would send his boat through the water, paying scant respect to the swift tidal currents of the Piscataqua, won the instant, lasting admiration of athletic boys. You felt instinctively that the man was enjoying this simple open-air pleasure as keenly as if he were a child of ten; that the mere fun of pulling himself about the rockbound little harbor, and of playing with the far from sportive fish still to be caught there, was enough to make the days when he could do it worth living.

Or perhaps you would yourself be rowing past the old Wentworth place, and would find him sitting on the pier, with the lilacs, and the great chimneys with their wilderness of rambling roof, behind him. You would stop to pass the time of day, as the saying is, to talk for a few minutes of whatever might turn up. As likely as not, the subject would be the last new novel or story that was really amusing. For Mr. Parkman liked to be amused, and found few things more amusing than a good, rattling story read aloud to him. Here, without any affectation of literary doctrine, his taste was romantic. If I remember rightly, he had small patience with that considerable body of modern fiction which gravely claims the right to bore you. If he had ever seemed self-conscious enough to warrant such a surmise, you might sometimes have ventured to wonder whether the consciousness that, as a serious historian, he had never presumed to bore anybody, might not have whetted his indignation at solemn scribblers of pretentious make-believe. Such an idea, though, could never have occurred to you in his presence. The normal impersonality, the animated objectivity of his talk, the frank, idiomatic raciness of his phrase, the wholesomeness of his nature, made you forget that he had ever written anything. You thought of him, by and by, just as a remarkably friendly human being. You forgot even that he was not exactly of an age with you. Like his own literary style, which kept pace so sensitively with the best literary feeling of his day, the man himself was steadily contemporary.

There were times, too, far fewer than one would wish, when one saw him even more intimately. In the midst of all this vigorous open-air life, he was really an invalid still. If you happened to call at the house when he was staying there, the chances were that he would not appear. Sometimes, doubtless, he was at work. Oftener I take it, he was resting, or struggling with the malady which so often made even the excitement of meeting anybody the source of acute suffering. It is only since one has read his autobiography, however, that one can realize what his suffering was; in real life one never caught a glimpse of it. Either one did not see him at all, and inferred that he was a bit indisposed; or perhaps one found him very silent; beyond this, there was nothing to suggest that he was not as strong, as well, as the best of us. Now and then, however, — generally when his lameness bothered him more than usual, — he liked you to come and sit with him a little while. I saw him thus alone perhaps half a dozen times.

The last time of all I remember best. It was a few weeks before his seventieth birthday. I had been taking tea near by, and, hearing that he was laid up for the moment, ventured over to see him while I smoked my cigar. I found him quite by himself, and seemingly glad of a visitor; for, in the growing twilight of that August evening, he talked more than I ever remember to have heard him talk at once before. As always, in his talk with me, he had something to say about Harvard. Like any man of his time and traditions, he had more doubts than a few concerning the quality of youth which is now growing up even in that most respectable institution of learning. Just at that moment, however, he was full of interest in a new book of college stories, which told most sympathetically of Harvard life as a contemporary undergraduate sees it; and to Mr. Parkman's mind — as well as to mine — they had two very reassuring merits: they could not possibly bore you, and they could not possibly have been written by anybody but a gentleman. So our last words about Harvard were cheerful ones: however languishing the finer traditions sometimes seem, they show themselves there, ever and again, as freshly vital as ever.

Then, somehow, the talk turned upon the Puritans. Some little time before, I had written a short life of Cotton Mather. Little as I had found in Mather's faith or practice which I could literally or actually share, I had found in the strength of his conservative enthusiasm something which commanded my heartiest sympathy. Now what in the end I found most sympathetic in Mr. Parkman himself was the enthusiastic strength of his conservative feelings. No one ever seemed to me more heartily to hate the folly of abstractions, more prudently to dread the sacrifice of what we know, for all its faults and errors, to be present good, for the sake of conceivable, but in no wise certain, future benefit. The trait I have in mind, which pervaded his serious talk, animates his well known writings about Woman's Suffrage. When it came to talking of the Mathers, however, I found, as I had found before, that he could not in any way share my sympathy for the conquered orthodoxy of New England. Their narrowness, their pettiness, their limits, their tyranny, and above all their absurdities, were to him almost the sum of their character. Sewall's Diary either amused or provoked him. What seemed to me the noble side of it — the passionate eagerness to preserve unaltered what the Puritans believed to be their divinely sanctioned system of faith and government — Mr. Parkman could not quite appreciate or care for. He did not like the Puritans; and what he did not like he could fervently condemn. He could not feel, as I felt, that what I liked best in him — his wholesome conservatism of impulse — differed from what I liked in them only as the nineteenth century differs from the seventeenth. In truth, I take it, this instinctive dislike of Puritan dogma and character marked him as a man of an older generation than at first he seemed. He was old enough to remember the days when, in New England, orthodox Calvinistic bigotry was actually dangerous to the freedom of thought in which both he and I believed. So to him the Puritans were once for all what Secessionists are to the surviving Republicans of the early days.

One more passage in the talk of that evening I remember. Speaking somehow about the time of the Rebellion, he said very simply that to his mind one of the chiefly deplorable things about our civil war was that it had disturbed, had dimmed, the concrete ideal of character and conduct traditionally kept before the youth of America. Up to the war, the one great ideal figure had always been the figure of Washington, — a figure alike worthy for its moral dignity and for its personal. Since the war, he said, we have heard too little of Washington; that is almost the worst thing the war has done for us. For the less, as Americans, we think of Washington, the worse for America.

So he talked on; and by and by I took leave of him in the dusk. I never saw him again.

Too personal for record these slight remembrances may seem. Yet, if they serve to tell how the solemnly traditional personage called "Parkman" could merge insensibly into the friend whose loss came as a personal grief, they may perhaps serve, in time to come, better to preserve his memory than if they had been left unwritten.

1894. BARRETT WENDELL.

HENRY WARREN TORREY

Henry Warren Torrey, Professor Emeritus of Ancient and Modern History in the University at Cambridge, was born in Roxbury, Massachusetts, November 11, 1814. He was the son of John Torrey and Marcia Otis, daughter of Henry and Mary Warren of Plymouth. He was educated in the Adams Grammar School in Boston, where he received a Franklin Medal at ten years old, losing his father in the same year (1824). He was a pupil of the Boston Latin School under Master B. A. Gould, completing the five years' course in four years, from 1825 to 1829, and graduating from Harvard College in 1833, where he stood second in rank, the late Professor Bowen being first.

He was usher at the Latin School under Master F. P. Leverett, whom he assisted greatly in the compilation of his Latin Lexicon. The English-Latin part of this book was entirely prepared by him, and the part of it from A to C was an original work, where Mr. Torrey had in sober earnest attempted that almost impossible task, the preparation of a book really worth the name, to assist in translating good English into good Latin. At this stage of the work he was forced to desist, and for the remainder to confine himself to a recasting of "Ainsworth," a task singularly uncongenial to Mr. Torrey, whose fine mind was one of the first to recognize the worthlessness of Ainsworth's Dictionary, — a work to be recast only by being cast into the fire.

His service on the two Lexicons had practically ruined his eyes; but this loss did not deter him from studying law at New Bedford in the office of his accomplished and ever genial uncle, the Hon. Charles Henry Warren. He was admitted to the bar, but never practised, on account of his eyes. He kept school in Providence for a year and a half, and made a voyage to the Azores with Hon. William W. Swain. This was one of the many vain efforts of that warm-hearted and excellent man to restore health to his son Robert, whose lovely character, tried in the furnace of scarcely intermitted suffering, only seemed to approach nearer to the angels with every hour that brought him to his end at the age of twenty-one.

Mr. Torrey was again instructor in the Latin School in 1842, and Tutor in History and Instructor in Elocution at Harvard College from 1844 to 1848. For the next eight years he kept a girls' school at No. 5 Hamilton Place in Boston, with his sister, which attained the highest reputation. In 1856 the McLean Professorship of Ancient and Modern History, for many years vacant through the meanest of political intrigues, was conferred on him. He immediately took a year of European travel, and returned to discharge the duties of his professorship in 1857. He was engaged in its active labors till 1866, and was then appointed Professor Emeritus. While holding this title he was chosen on the Board of Overseers, and died on the anniversary of the death of Washington, December 14, 1893. He was elected to the American Academy, November 12, 1856.

Mr. Torrey's active life was that of a teacher. It is of little moment to speculate whether he might not have distinguished himself in some other line. He was emphatically an instructor, and not a few of his pupils are yet living who feel that he was the best instructor they ever had, — the one to whom they owe most.

He was a teacher according to the old fashion; that is, being a scholar and a student himself, he expected his pupils to be scholars and students on the lines he laid down for them. He impressed upon all of them the idea that he who will not work cannot learn; and that both working and learning must be done in the line of duty, — that of subjecting one's own mind and energy to the control of those in rightful authority. He never swerved from this rule, yet he administered it with such unvarying sympathy and kindness that no pupil who was worth teaching ever felt any sense of coercion or harsh pressure, or was other than stimulated and braced by his kindly insistence. As soon as his pupils had done their work his began. He supplied to them an amount of knowledge, not only on the specific subjects they were studying, but on a score of others, which they never could have acquired without repeating his own indefatigable labor. From first to last this knowledge was unerringly accurate. A mistake of fact was to Professor Torrey simply an untruth; and to state a name or a date incorrectly was to falsify. Whatever was not right was wrong.

But he did not end with facts. He combined his vast stock of information into an organic whole by the spirit of a philosophy which soared far above the mere earth of accumulation which makes up so much of human learning. The effect of this constructive power on his pupils was startling, if such a word can be applied to so precise and gentle a character. A student might come before him, fancying he knew a good deal of history for a young man; he might have studied it, read it, or even, as a boy does, written it; then would Mr. Torrey reveal to him, not only how little all this information was, but how infinitely greater and better in kind was the Philosophy of History, — the relation of nation to nation, of period to period, and of all to the mighty scheme of Providence which he saw working through all time. Yet in all this setting forth the great subject in its true perspective, and making the amount of his pupils' knowledge appear very small, there was absolutely nothing unkind, no undervaluing a single real acquirement. On the contrary, he made the value of every pupil's attainments far greater than it would have been had they gone on without him in their own boyish way and spirit.

This power of lighting up the specific subjects that he treated was nowhere better shown than in his instruction on the Constitution of the United States. Not a few of his pupils have been called upon to serve in positions of authority under that august instrument; and none of them would deny that they received from his instructions an understanding of their practical duties which no other teacher, public or private, could give.

But more than one teacher is learned and stimulating, and yet is entirely without two things which were the very life and soul of Mr. Torrey's instruction: first, his affectionate heart, which went out to every pupil who would accept it as to a personal friend; and, secondly, his supreme allegiance to duty, wherewith he tried, in that absolute simplicity which was his nature, to inspire his pupils, as might an elder brother who knew that if they did not follow the way of right they never could accomplish anything worth doing. That nobody could really be a good scholar, or a good historian, without being a good man, was the core of all his teaching; and it was worth while to be under him, if only to learn this one thing.

Such was the man in the class-room, clinging to the old-fashioned discipline and methods, which he might well think the best, because his own glowing personality had warmed them into a vital force that needed no further kindling from modern devices. There was a certain veil of formality about his presence which might at first deter one from penetrating into a more intimate knowledge. Yet something about his ready smile and his eager manner, never cold though always courteous, encouraged his pupils to bring to him personal requests and difficulties, which were invariably received half-way, and proved the ready key to outside acquaintance. The threshold once passed, it seemed amazing that one ever could have considered him formal. No heartier or more genial friendship ever glowed in a human breast. He had been brought up under one of the most brilliant wits of his day, the late Judge Warren, already named; and an inherited playfulness, softened by an ever-present sense of propriety and modesty, made his conversation inexpressibly delightful. It was so to all; but it was most peculiarly so to such as having been his pupils became after an interval his colleagues in instruction. To them his house and his heart were open in a combination of the elder and the equal hard to describe. There was nothing that mind or heart desired to fill the void caused by exhausting daily work, to heal the blows received from daily stupidity, waywardness, and ingratitude, which a younger teacher could not find in his company, — sympathizing with one's annoyances, confirming one's purposes, elevating one from depressing doubts. It had been much to sit at his feet and obey him; it was infinitely more to sit by his side and love him; and the world is darker since his presence has been withdrawn.

Having given years of such public and private work to the College, he saw with pain that methods and aims with which he found it hard to sympathize were in the ascendant; but there was no want of loyalty in the efforts which he made to accept them; and though he distrusted seriously the indefinite extension of an elective system, that system received no better assistance than he gave it in his advanced courses. The best of the old was equal to the best of the new. It was touching to see how, on not a few occasions, his faultless pen, from which flowed the purest of old classical English, was employed to give adequate form to matter which certainly did not originate with his suggestions.

His nature was sensitive; but it was not the sensitiveness of a morbid or selfish constitution, — it was the sensitiveness of his Pilgrim ancestors, — the sensitiveness of a conscience which loved and courted the gaze of Heaven, and shrank from every transgression of absolute right as an insult to the God of truth. His untiring industry, his capacious and penetrating intellect, his ardent energy, were all directed and chastened by his ever living sense of Christian duty; and his work, which may pass unchallenged the severest tests of practical humanity, was devised, carried on, and completed in strictest view of the higher scrutiny which belongs to an eternal standard and an unseen Judge.

1894. WILLIAM EVERETT.

FOREIGN HONORARY MEMBERS.

THE MARQUIS OF CALIGNY.

An ancient family, which since 1660 had produced a succession of military engineers, became extinct by the death of the Marquis of Caligny; several of its members were esteemed by Vauban, and their works are yet well known to civil and military engineers.

Anatole François Hüe, Marquis de Caligny, was born at Valognes (Manche), May 31, 1811. The son of Bernard-Henri-Louis Hüe, Marquis de Caligny, and Eugénie-Marie-Léonore-Avice de Fermanville. He was related to many of the illustrious families of France, and popular tradition affirmed that his descent could be traced from Charlemagne; however this may be, it is certain that he was the last of a distinguished group of hydraulic engineers, among whom may be mentioned Louis Roland de Caligny, founder of the port of Cherbourg.

De Caligny entered the College of St. Lô in 1822, where he first met Leverrier, who became his intimate friend. This friendship, based on a similarity of tastes, remained constant and unalterable, in spite of the great astronomer's changes of opinion. Caligny remained firmly Legitimist and Catholic, for him the political changes subsequent to 1789 were as if they did not exist; with this difference, the two were as brothers.

At the age of sixteen, he began the study of philosophy at Valognes, in order to be near his family, who resided in the Château de Flottemanville, a league from that town. The next year he took up his residence at the Château, where he conceived the first ideas of his inventions.

Following the advice of the Cherbourg engineers, he removed to Paris in 1836. Here he recommenced his experimental investigations, which were to be pursued with little interruption for half a century.

He soon made the acquaintance of Coriolis, who, appreciating his researches, advised him to embody them in a report to the Institute. In conformity with this suggestion, he prepared a memoir on "Hydraulic Machines with Oscillating Liquid Columns," which was presented to the Academy and referred to a committee consisting of MM. Poncelet,* Coriolis, Gambey, and Seguier, who reported so favorably upon it, that the Academy awarded him the Montyon Prize * in Mechanics, which had just been established. Caligny's invention is thus described in the report of the committee: "The happy idea which distinguishes this machine, and characterizes it as a veritable invention, is the discharge through a vertical tube, after an upward oscillation, without the loss of any living force except that consumed by friction; that is to say, by depressing very slightly the centre of gravity of the fluid column to be discharged. Without doubt the machine appears simple both in conception and construction, but this simplicity only enhances its merits."

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* Poncelet was his predecessor in the American Academy.

From this time Caligny's success was assured. He was the discoverer of a new branch of hydraulics, namely, that relating to oscillating liquids; and he published from time to time accounts of his researches, which were remarkable both for the methods employed and the results obtained. To these researches he devoted his life, never attaching himself to any administration, nor taking part in any private enterprise; he even refused to take patents for his inventions, preferring to devote himself with indefatigable zeal to the disinterested pursuit of science.

On several occasions his rights of priority were disputed, but they were always easily established by means of his publications in the transactions of the French Academy. His investigations were brought together in 1883, in two volumes entitled, "Theoretical and Experimental Researches on the Oscillations of Water and Hydraulic Machines with Liquid Oscillating Columns." Prizes were awarded to his machines at all the International Exhibitions, and he received numerous diplomas from different European Academies.

The following succinct account of his first apparatus is thus given by M. Boussinesq: —

"From the bottom of a reservoir containing water at rest, a long horizontal or slightly inclined conduit issues, having its further end terminated by a vertical pipe of the same diameter as the conduit, and rising some distance above the level of the reservoir. It is proposed to raise and discharge the water from the top of this pipe. For this purpose, a valve movable around a horizontal axis, manipulated from without, separates the empty vertical pipe from the conduit filled with water under pressure. The valve, being at a given moment released, is raised by the water which begins to rise in the pipe, and that in the conduit also, but only little by little, on account of its great mass.

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* This prize consists of a gold medal valued at 500 francs.

Its living force attains its maximum at the instant when the liquid in the pipe rises to the reservoir level. This living force is capable, except for the slight loss due to friction, of carrying the ascending liquid column as high above the reservoir level as its point of departure was below it. As only a part of the force has been consumed at the moment when the liquid begins to pour out above, the discharge continues until the whole column in motion has been brought to rest. But at this moment the valve falls by its own weight, and opens at the same time a short horizontal tube which it closed while it was raised, thus offering a free exit for all the water in the vertical pipe, which thus rapidly escapes into a second reservoir just above the level of the valve. The liquid contained in the horizontal conduit during this time comes to rest, and then begins to oscillate by raising the valve; then a new period of ascension with discharge begins."

If Caligny's experiments had not been realized for half a century, might not this description have been taken as a project for perpetual motion?

In 1868, the Administration of Roads and Bridges built, on a working scale, Caligny's new system of saving basins for canal locks, at the Aubois Lock, upon the lateral canal of the Loire.

Here he made many experiments with the help of the Administration. Inspector General Vallès accompanied him, made a report to the Institute, and published a memoir entitled, "Experiments made at the Aubois Lock to determine the useful Effect of the Apparatus by the aid of which M. de Caligny greatly diminishes the Consumption of Water in Navigable Canals."

The following description of this apparatus is taken from the United States Report* on the Vienna International Exhibition.

DESCRIPTION OF THE AUBOIS CANAL LOCK.

Process invented by the Marquis of Caligny. — We know that for each passage through a lock, whether up or down, a quantity of water must be drawn from the upper bay to fill up the lock to a height equal to the difference of level between the two bays, this height being called the lift of the lock, and the volume of water required for this purpose the prism of lift. The system invented by the Marquis of Caligny and applied to the Aubois lock has for its object to diminish this waste by causing water from the lower bay to ascend into the lock-chamber when the latter is to be filled; and also by making part of the water in the lock-chamber ascend to the fore-bay when the lock-chamber is to be emptied. The system is founded on the known properties of oscillating liquids.

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* Civil Engineering, Public Works, and Architecture. By William Watson, U. S. Commissioner.

The work consists (omitting the details): —

First. Of an aqueduct connecting the lower gate-chamber with two separate reservoirs, U (upper) and L (lower), situated behind the upper gate-chamber.

Second. Of a discharging-channel or saving-basin, connecting the reservoir L with the lower bay by a sluice; the other reservoir, U, communicates with the upper bay.

Third. Of two vertical movable pipes, *u*, *l*, open at both ends, and resting upon two circular openings made in the walls of the aqueduct. One of these pipes, *u*, is placed in the reservoir communicating with the upper bay, and the other, *l*, in the one communicating with the lower bay. When these pipes are lowered upon their seats, the upper extremity of the aqueduct is shut. If we raise the upper pipe, *u*, the water from the upper bay enters the aqueduct; if, on the contrary, we raise the lower pipe, *l*, the water from the lock goes into the saving-basin, or *vice versa*, according to their respective levels.

The manner of working is as follows. Suppose the full lock is to be emptied; we raise the pipe *l*, the water from the lock-chamber passes through the acqueduct under the pipe, and enters the saving-basin, which is supposed to be on a level with the lower bay. After having held the pipe *l* raised during a few seconds for the water to acquire its velocity, we drop it back upon its seat; the water in the aqueduct, having no issue under the pipe *l*, rises in the interior of both *l* and *u*, and pours over their tops into the reservoir U, connected with the upper bay. Thus, on account of the living force of the moving liquid mass in the aqueduct, a part of the water is carried into the upper bay. When this first oscillation has ceased to cause the water to overflow from the pipes *u* and *l*, we recommence the same operation by raising again the pipe *l*; a new column of water issues from the lock; we interrupt again its flow under *l*, and a new oscillation produces a new overflow into the upper bay. As this operation is repeated the lock is emptied, one portion into the saving-basin and thence into the lower bay, another portion into the upper bay.

Without entering further into the details of the operation, the results may be stated as follows.

This canal lock has been in operation since 1868, and we find: —

First. That seven or eight oscillations suffice to fill or empty the lock in five or six minutes.

Second. That for filling the lock without using the reserve in the saving-basin the volume of water taken from the lower bay is 0.41 V, V being the prism of lift, so that the saving by this operation is about two fifths of V.

Third. That during the process of emptying the volume sent into the upper bay is about 0.386 V, without considering what is saved by the final oscillation. The sum of the volumes raised by the two operations is (0.41 + 0.386) V = 0.796 V. By utilizing the great final oscillations the saving amounts to 0.90 V.

This system, while it economizes the water used, produces neither lowering in short bays, nor exaggerated velocities in the narrow passages, and constitutes an ingenious use of the properties of liquids in motion. Its application to the Aubois lock cost about 40,000 francs, but much of this was owing to the difficulties of position and the nature of the soil, which required special precautions. A considerable economy might be made by placing the aqueduct along the side walls of the lock.

AWARD. — The jury for Group XVIII. awarded to the Marquis of Caligny the Medal for Progress.

At this time, M. de Caligny was elected Corrresponding Member of the Institute of France. On the death of Clausius, Caligny became Dean of the Corresponding Members of the Institute; and at this time he was elected into the American Academy to fill the vacancy thus made.

On the occasion of the Universal Exhibition at Paris in 1889, a considerable space in the Department of Agriculture was allotted for the display of a number of Caligny's ingenious contrivances for raising water, and the author of this notice had the pleasure of seeing these machines in operation, and of observing how thoroughly they were adapted to the requirements of agricultural irrigation.

M. de Caligny rendered a service to history and to military art by publishing six octavo volumes of the Military Memoirs of Marshal Vauban and the engineer Hüe de Caligny, his ancestor, extracted from his personal archives. This work was published in Paris in 1841. It will be remembered that his three elder brothers died for their country; one killed in 1807 at the battle of Eylau, the others in 1813 at Lutzen. During a visit to Versailles in 1878, Caligny showed the author a list of his military ancestors, among whom were several who served in America under Rochambeau.

Toward the end of his life his sight became impaired, but this affliction was tempered by the care and assistance of his courageous wife, who served him as secretary.

His death occurred on the 24th of March, 1892, in the eighty-first year of his age. The local journal, "Le Petit Versailles," says of him, "C'était un homme de bien, dans toute l'acception du mot." To this just appreciation, Catalan, his intimate friend for more than half a century, adds, "Il était simple et bon." The words inscribed upon Gay's monument might, with equal truthfulness, be Caligny's epitaph: —

> "Of manners gentle, of affections mild;
> In wit, a man; simplicity, a child."

PAPERS PUBLISHED. — MEDALS AND DIPLOMAS RECEIVED.

1837. New Principles on the Oscillations of Water, and New Hydraulic Machines.

This was made part of the instruction given at the Polytechnic School at Paris.

1838. New System of Canal Locks; and a New Apparatus to raise Water without any movable Valve.

1839. On a New Hydraulic Motor with Oscillating Floats.

This year he joined the Paris Philomathic Society.

1840. A Report to the Institute on an Hydraulic Motor of his invention.

Intermittent and Oscillating Fountains.

Experiments on the Oscillations of Water in a large Conduit in Paris.

1841. Intermittent Fountains under the Sea.

1843. Experiments on the Motions of Waves.

Experiments on a large scale with an Hydraulic Motor with Oscillating Floats.

1844. Experiments on Conical diverging Mouthpieces, and on several kinds of Liquid Waves.

On a New Blowing Engine, or Air Compressor; for which he received a Gold Medal from the King of Sardinia.

1845. On Breast Wheels.

Historical Researches on Hydraulics.

Elected Corresponding Member of the Royal Academy of Sciences at Turin.

1846. Studies in Hydraulics. Second System of Compressors.

1847. Experiments on a Model of a Canal Lock and on Two Hydraulic Motors with Valvular Pistons. On Vertical Wheels, with Curved Floats, and fed from within.

1848. Observations on Water Vortices.

1849. Description of a New Hydraulic Machine.

1850. Experiments on Mouthpieces, Curbs, Vortices, Waves, and the Friction of Water.

Experiments on a new Machine founded on a Phenomenon of Suction just discovered.

Elected Correspondent of the Royal Society of Sciences at Liège.

1852. New Draining Machine operated by Means of Sea Waves.

Observations on the Waves at Fécamp, France.

Gold Medal from the Central Society of Agriculture.

Experiments on several pieces of Apparatus of his invention.

Invention of an Automatic " Barrage."

Description of a Pump without Piston or Valves, applied in several localities.

Description of a New Apparatus; also a Valvular Piston for working a Pump by means of a Variable Fall of Water. This Motor was used at the Palais de l'Elisée.

1855. The two preceding years were employed in making experiments for which he received a Medal of the First Class at the Paris International Exhibition.

Experiments on a New Hydraulic Machine.

Experiments on a means of Diminishing the Resistance of Water in Curves by Concentric Curved Blades.

1856. Experiments on the Regulators of Hydraulic Machines, on Liquid Surfaces, and on the Theories of several pieces of Apparatus.

1857. New Machines for Drainage in Special Cases. New Means of Drainage by the Suction of Sea Waves without any moving Piece.

1858. Observations on the Motion of Water in Respect to the Geological Formation of the Valleys through which it flows.

1859. Properties of the Single-valved Hydraulic Ram transformed into a Blowing Engine.

M. de Cuyper, Professor of Mechanics at the University of Liége, published a memoir the same year to defend the rights of M. de Caligny with reference to Blowing Engines or Air Compressors, one form of which had been employed for driving the Mt. Cenis Tunnel.

1860. New Methods of Compressing Air by means of a Waterfall.

1861. Observations on the Effects of Heat in the Reversed Siphons of the Compressors at Mt. Cenis.

1862. Description of a New Vertical Water-wheel with Plunging Tubes and Liquid Oscillating Floats.

On the Vibration of Liquid Columns.

On the Waves of the Sea at Fécamp.

1863. Experiments on the Phenomena of Suction; on Waves, etc.

On an Improvement in Turbines.

1864. Studies on Earthquakes.

It was on the occasion of the employment of his compressors that he was nominated Chevalier of the Order of St. Maurice and Lazare in 1864, and Chevalier of the Order of St. Gregory the Great in 1865.

1866. Considerations on the Nature of Liquid Friction under Great Pressure.

1867. Application of a New System of Canal Locks to Chains of Locks.

Transformation of Rotative Pumps into Hydraulic Motors.

New Machines for Drainage at any Depth.

1868. Result of the Experiments made by the International Jury of the Paris Universal Exhibition of 1867 upon Caligny's Apparatus without Valves with an Oscillating Tube; for which a silver medal was awarded.

After the presentation of several notes, M. de Caligny was elected Correspondent of the Institute of France.

He was already Corresponding Member of the Royal Academy of Sciences at Lisbon; the Institute of Coimbra, Portugal; the Society of Engineers and Architects, Portugal; the Academy of Sciences at Philadelphia; the Pontifical Academy of Lincei at Rome; the Geographical Academy at Florence; the Royal Society at Prague; the Scientific Societies at Königsberg, Embden, Dantzic, Luxembourg, Zealand, and the Academies of Sciences at Rouen, Caen, Bordeaux, Cherbourg, Evreux, Avranches; also Member of the Imperial Society of Naturalists of Moscow, and Honorary Member of the Society of Physics at Geneva.

1869. On the occasion of the application of his system of locks, he was nominated Chevalier of the Order of Leopold of Belgium.

1872. Notes upon the Liquid Veins formed by the Blow of the Hydraulic Ram.

On Waves against Convergent Dikes and Inclined Beaches.

Presented to the French Academy of Sciences.

1873. Note on the Flow of Water over the Ostien Marsh.

Application of this was made by M. Moro, who recognized Caligny's priority.

Experiments on the Motion of Waves dashing up Inclined Planes.

Experiments upon the Effects of the lateral Communication of Motion by a running Stream traversing a Reservoir.

1874–75. Experiments made in company with M. Bertin, then Marine Engineer in the Arsenal at the Port of Cherbourg, upon an experimental Canal put at their Disposition by the Minister of Marine.

1876. Experiments at Aubois Lock, and New Studies on Canal Locks.

1877. Experiments on several Kinds of Waves, and on Back-water.

1878. Experiments made with M. Bertin on the Action of Waves on Sailing Vessels; on their Action on Beaches, and on Artificial Rock-work.

The Jury for the Paris Exhibition of 1878 awarded him a Silver Medal.

1878–79 New Studies on the Hydraulic Ram.

These principles were applied by M. Chemin in different ways in laying the foundations of locks.

The Foundation of the Ancient Port of Cherbourg, 1686–1739 to 1743–1758. Published in Collaboration with M. Bertin.

1880–82. Theoretical and Experimental Researches on the Oscillations of Water and Hydraulic Machines with Oscillating Liquid Columns. In two octavo volumes.

1881–82. Experiments at the Cherbourg Arsenal with Bent Tubes; at the Aubois Lock, upon the Automatic Movement of the System; and at Flottemanville on a Lifting Machine which was employed for Irrigations at great heights.

1883. Realization of the Automatic Working of the System applied at the Aubois Lock with neither Saving-basin, Valve, nor Cataract.

1884. For his great work, he received a Gold Medal from the Universal Exhibition at Amsterdam, and a Diploma of Honor from that at New Orleans.

Elected Corresponding Member of the Royal Academy of Sciences at Madrid.

New Experiments at the Aubois Lock.

1885. Gold Medal from the Universal Exhibition at Antwerp.

Experiments on a New Machine for compressing Air by Means of a Waterfall.

1887. An improved form of his machine for raising water was erected at Flottemanville. This machine is rustic in its character, and well adapted to the use of country laborers.

1888. A new Hydraulic Machine of a much greater efficiency than his other apparatus.

Elected Honorary Member of the Institution of the Royal Netherland Engineers, and of the Royal Belgian Academy of Sciences.

The Diploma of Honor was given him by the Universal Exhibition of Brussels; a Gold Medal from that of Barcelona, and a Diploma of Honor from that at Melbourne. Other Medals and Diplomas were given which need not be mentioned in detail.

1888–92. Notes on Improvements applicable to his Inventions.

1894. WILLIAM WATSON.

BENJAMIN JOWETT.

BENJAMIN JOWETT, Master of Balliol College and Regius Professor of Greek in the University of Oxford, died on October 1, 1893. He was born at Camberwell in 1817, and attended St. Paul's School in London. He was a student of Balliol, and received his Bachelor's degree at Oxford in 1839, with a first class in *Literæ Humaniores*. He became Tutor of Balliol in 1842, and Master of Balliol in 1870. He held the office of Vice-Chancellor of the University from 1882 to 1886. He was made Regius Professor of Greek in 1855, and he held this office until his death. He received the honorary degree of Doctor in Theology from the University of Leyden in 1875, and that of Doctor of Laws from Edinburgh in 1884, from Dublin in 1886, and from Cambridge in 1890. His service of more than half a century at Oxford was a memorable one. It may safely be said that no man ever exerted a stronger personal influence upon the undergraduates of Oxford, and no man has ever gone to his rest with the benedictions of a longer line of grateful pupils. His own appreciation of the respect and love which his long and faithful services inspired may be seen in the dedication of the third edition of his translation of Plato, published in 1891: "To my former pupils in Balliol College and in the University of Oxford, who during fifty years have been the best of friends to me, these volumes are inscribed in grateful recognition of their never failing attachment."

Professor Jowett will always be best known to the literary world outside of Oxford by his translation of Plato, which for the last twenty-three years has been a standard classic. This work is addressed to the "general reader," who is assumed to want to know what Plato wrote and how he expressed it, without caring for minute details of scholarship. With this view, the translator has not hesitated to rewrite a passage "as the author would have written it at first if he had not been nodding," or "to supply anything which, owing to the genius of the language or some accident of composition, is omitted in the Greek, but is necessary to make the English clear and consecutive." This process gives brilliant results where it succeeds, but it makes sad work where it fails. All scholars know well the brilliancy of Jowett's Plato as a whole; and all careful students of Plato are often doubtful, to say the least, whether in a difficult argument it is Plato or his translator who is "nodding." Jowett's translations of Thucydides, published in 1881, and of Aristotle's Politics, published in 1885, follow the same principles, and have the same felicities of style and expression which mark his Plato.

A generation ago Dr. Jowett was best known to the world as the author of the essay on "The Interpretation of Scriptures," published in the famous volume entitled "Essays and Reviews." It is almost impossible now to understand the furious excitement which this volume aroused in the theological world. It was a bold and vigorous manifesto of the Broad Church in England against the narrow limits within which it was maintained English theology had confined itself, as contrasted with the free range of German speculation. The book and all its authors were assailed at once, not merely by arguments, but by abuse and persecution. It is well known that Dr. Jowett's salary as Regius Professor of Greek at Oxford, for several years after the publication of the "Essays and Reviews," was confined to the fixed stipend of forty pounds a year, which was assigned to the professorship by Henry VIII. The North American Review, which then represented the conservative Unitarianism of Harvard University, assailed the volume under the title of "The Oxford Clergymen's Attack on Christianity." The more sober judgment of England on this almost forgotten controversy may be seen in the facts that the editor of the "Essays and Reviews," and the writer of the leading essay, is now the Right Rev. Frederick Temple, D. D., Lord Bishop of London, and that no man ever held a more secure or more exalted position in the Church of England than Dr. Jowett in his later years.

Dr. Jowett was made a Foreign Honorary Member of the Academy, May 27, 1873.

1894. WILLIAM W. GOODWIN.

CHARLES MERIVALE.

THE historian of the Romans under the Empire died in December last. He was born in 1808, and was therefore in his eighty-fifth year at the time of his death. The leading facts of his long life may be stated briefly. He was educated at the University of Cambridge, where he received the Bachelor's degree in 1830. From 1838 to 1840 he was one of the Preachers to the University, and in 1861 was Hulsean Lecturer. He was Rector of Lawford in Essex County from 1848 to 1869. During the last six years of this period he was Chaplain to the Speaker of the House of Commons. In 1864, and again in 1865, he was chosen to deliver the Boyle Lecture at Whitehall. In 1869 he was made Dean of Ely. This last position he held till his death. He was elected a Foreign Honorary Member of our Academy, May 24, 1870.

Dean Merivale belonged to a literary family, his father, his brother, and his nephew being authors of reputation. He was himself an author on an extensive scale. In addition to lectures and sermons published from time to time, and some critical work as editor of Latin texts, he published the following historical works: —

A General History of Rome. 1 volume.
The Fall of the Roman Republic; — a Short History of the Last Century of the Commonwealth.
The Roman Triumvirates. 1 volume.
History of the Romans under the Empire. 8 volumes.
The Continental Teutons. Conversion of the West.

The Conversion of the Roman Empire. (Boyle Lecture for 1864.)
The Conversion of the Northern Nations. (Boyle Lecture for 1865.)

Also the following works of a non-historical character : --

Open Fellowships: a Plea for submitting College Fellowships to University Competition.
Homer's Iliad in English rhymed verse.

The titles of these works show at a glance the direction of Dr. Merivale's activity as a student and writer. The period of the transition from the ancient to the mediæval world had for him an irresistible attraction. Both his historical and his religious instincts found there subjects on which they could have ample play. It was indeed a period of momentous issues, of large and lasting transformations, — a period in which every political and religious institution of the civilized world seemed more than once to be at the point of destruction. An old order was passing away amid throes and disasters; a new order was painfully struggling into being. The Republic had failed to develop its constitution in harmony with the position its conquests had given it. The meeting of the Roman citizens in their centuries and tribes answered passably as the sovereign power, while Rome's dominion was limited to her own neighborhood. When her arms had carried her sway over the best portions of three continents, her city organization became simply and absurdly impossible as a constitution for so great a territory and such a multitude of subjects. The difficulties that modern England has on her hands, owing to the growth of her dependencies, are as nothing in comparison with those that confronted the Roman Republic. For the English have a representative Parliament, in which, when the English and their colonial fellow subjects agree in desiring it, colonial representatives may take their seats side by side with the members for the three kingdoms. But Rome had no representative body. The citizens who lived in Gaul, or in Asia Minor, could make their voice felt in the government only by going to Rome to vote. The world-wide Republic, organized as a city, was unable or unwilling to recognize its new position. It had ceased to be Roman when it became the civilized world. It could not remain a republic, for the elements of its population were too heterogeneous and scattered to agree in anything. The ancient world of city constitutions had reached its term.

The period of Dean Merivale's studies covers the transformation of the Republic into the Empire. The same period includes also the early stages of that other historical movement which has so deeply affected the motives, hopes, and behavior of civilized men. His chief work, the "History of the Romans under the Empire," begins with the struggles that marked the fall of the Republic, and carries the story on to the death of Marcus Aurelius. It covers, therefore, nearly two centuries of Christian history,—the two centuries in which the new religion had its hardest contest with the superstitions and the philosophies it came to supplant.

Strange to say, at the time when Dr. Merivale began his work, this great period was without adequate historical treatment in English. Arnold did not come down so far, and Gibbon took up the story after this period was passed. Even now it would be difficult, apart from Dean Merivale's own work, to name any extensive and authoritative English treatise on the period. Doubtless one of the reasons why other writers have avoided the time is that which constituted one of its attractions for Dr. Merivale. The sources are so varied and so copious that the man who undertakes to master them has great need of courage. No other period of ancient or mediæval history has anything like the same bulk of material to be read and sifted. In fact, one has to come down to comparatively recent times to find sources rivalling those of this period in variety and volume.

How far Dean Merivale has succeeded in making the most of this copious material, I shall not be so presumptuous as to attempt to pronounce. Some qualities of his work are obvious on the face of it. He is admitted on all hands to be minutely accurate as to his facts. This, though not perhaps the very highest quality of an historian, is at least one of the highest. It is much to know that your author states nothing as a fact without full and adequate authority; that, when there is a conflict of testimony, or a question which the sources do not clearly settle, he does not allow his imagination to supply, even by ingenious hypothesis, the defects of his material. Herein lies, as it seems to me, Dean Merivale's most striking characteristic as an historian. He has never, so far as I know, been caught in a slip as to the facts of a matter. Every page of his history bears evidence of the immense diligence and patience with which he compared and sifted the mass of original authorities on each topic.

But it may be doubted whether his history will ever be widely popular. The very excellence of which I have spoken is, for the general reader, not far removed from a defect. Most people who profess to read history demand, I suspect, more of literary and philosophic sauce than is offered in Dean Merivale's pages. He never aspires to what is commonly called eloquence. He has no burning denunciations, no glowing eulogies, no highly wrought descriptions of scenes or of characters. His anxiety seems rather to have been to be just, — to omit nothing essential, and to exaggerate nothing. In this spirit he found it necessary to point out some redeeming bits of white in the blackness of the bad Emperors whose doings he had to rehearse. Even Domitian finds, in his narrative, some mitigating touches in abatement of the deep infamy to which his name has been commonly assigned. This quality in Dean Merivale's work will not commend it to the taste of those who want black to be black and white white.

Again, his literary style is not marked by vivacity and polish. On the contrary, it is often cumbrous and heavy. It strikes one as the style of a man who was fonder of Latin literature than of English. The matter-of-fact way of looking at things, as well as the forms of expression and the structure of the sentences, are all suggestive of the Latin writers whose works must have been the author's daily bread for many a year.

Those who turn to history for relaxation or amusement will not be likely to find the History of the Romans under the Empire just what they desire. On the other hand, the scholarly few who wish above all things to know the exact truth, so far as it can be known, will always think of the late Dean of Ely with affectionate admiration; for he was himself a scholar to the tips of his fingers. He seems to have loved the dry, clear light of accurate scholarship with his whole heart. He has been called the "last of the great scholarly Deans." The words, we must hope, are not prophetic. The Established Church that finds room for such as he in its highest positions has something to be said in its defence. It can never be narrow or sectarian. If the new activity of the Church of England means that it has no longer room for great scholarly Deans, the world will have cause for looking on the change with some mixture of regret.

1894. S. M. Macvane.

The Academy has received an accession of three Resident Fellows, three Associate Fellows, and one Foreign Honorary Member.

The Roll of the Academy, corrected to date, includes the names of 190 Fellows, 98 Associate Fellows, and 68 Foreign Honorary Members.

MAY 9, 1894.

LIST

OF THE

FELLOWS AND FOREIGN HONORARY MEMBERS.

(Corrected to July, 1894.)

RESIDENT FELLOWS.—189.

(Number limited to two hundred.)

Class I.—*Mathematical and Physical Sciences.*—71.

Section I.—7.

Mathematics.

Benj. A. Gould,	Cambridge.
Gustavus Hay,	Boston.
Benjamin O. Peirce,	Cambridge.
John D. Runkle,	Brookline.
T. H. Safford,	Williamstown.
William E. Story,	Worcester.
Henry Taber,	Worcester.

Section II.—11.

Practical Astronomy and Geodesy.

Solon I. Bailey,	Arequipa.
Seth C. Chandler,	Cambridge.
Alvan G. Clark,	Cambridgeport.
J. Rayner Edmands,	Cambridge.
Francis M. Green,	Boston.
Henry Mitchell,	Boston.
Edward C. Pickering,	Cambridge.
John Ritchie, Jr.,	Boston.
Edwin F. Sawyer,	Brighton.
Arthur Searle,	Cambridge.
O. C. Wendell,	Cambridge.

Section III.—41.

Physics and Chemistry.

A. Graham Bell,	Washington.
Clarence J. Blake,	Boston.
Francis Blake,	Weston.
John H. Blake,	Boston.
Samuel Cabot,	Boston.
Arthur M. Comey,	Cambridge.
Josiah P. Cooke,	Cambridge.
Charles R. Cross,	Boston.
Amos E. Dolbear,	Somerville.
Thos. M. Drown,	Boston.
Charles W. Eliot,	Cambridge.
Thomas Gaffield,	Boston.
Wolcott Gibbs,	Newport, R. I.
Edwin H. Hall,	Cambridge.
Henry B. Hill,	Cambridge.
Silas W. Holman,	Boston.
William L. Hooper,	Somerville.
Henry M. Howe,	Boston.
Charles L. Jackson,	Cambridge.
William W. Jacques,	Newton.
Alonzo S. Kimball,	Worcester.
Leonard P. Kinnicutt,	Worcester.

William R. Livermore,	Boston.
Charles F. Mabery,	Cleveland.
A. A. Michelson,	Chicago.
George D. Moore,	Worcester.
Charles E. Munroe,	Washington.
John U. Nef,	Chicago.
Robert H. Richards,	Boston.
Theodore W. Richards,	Cambridge.
Edward S. Ritchie,	Newton.
A. Lawrence Rotch,	Boston.
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Charles R. Sanger,	St. Louis.
Stephen P. Sharples,	Cambridge.
Francis H. Storer,	Boston.
Elihu Thomson,	Lynn.
John Trowbridge,	Cambridge.
Harold Whiting,	Berkeley, Cal.
Charles H. Wing,	Ledger. N. C.
Edward S. Wood,	Boston.

SECTION IV. — 12.

Technology and Engineering.

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E. D. Leavitt,	Cambridgeport.
Hiram F. Mills,	Lowell.
Cecil H. Peabody,	Boston.
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Andrew H. Russell,	Washington.
Peter Schwamb,	Arlington.
Charles S. Storrow,	Boston.
George F. Swain,	Boston.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

CLASS II. — *Natural and Physiological Sciences.* — 57.

SECTION I. — 11.

Geology, Mineralogy, and Physics of the Globe.

Thomas T. Bouvé,	Boston.
H. H. Clayton,	Milton.
Algernon Coolidge,	Boston.
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William M. Davis,	Cambridge.
O. W. Huntington,	Cambridge.
Jules Marcou,	Cambridge.
William H. Niles,	Cambridge.
John E. Pillsbury,	Boston.
Nathaniel S. Shaler,	Cambridge.
Warren Upham,	Minneapolis.

SECTION II. — 9.

Botany.

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Arthur B. Seymour,	Cambridge.
Charles J. Sprague,	Boston.
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SECTION III. — 19.

Zoölogy and Physiology.

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Robert Amory,	Boston.
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Henry P. Bowditch,	Boston.
Wm. Brewster,	Cambridge.
Louis Cabot,	Brookline.
Harold C. Ernst,	Boston.
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Edw. G. Gardiner,	Boston.
Samuel Henshaw,	Cambridge.
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Edward L. Mark,	Cambridge.
Charles S. Minot,	Boston.
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Samuel H. Scudder,	Cambridge.
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SECTION IV. — 18.

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David W. Cheever,	Boston.
Benjamin E. Cotting,	Roxbury.
Frank W. Draper,	Boston.
Thomas Dwight,	Boston.
Reginald H. Fitz,	Boston.
Charles F. Folsom,	Boston.
Richard M. Hodges,	Boston.
Oliver W. Holmes,	Boston.
Frederick I. Knight,	Boston.
Francis Minot,	Boston.
Samuel J. Mixter,	Boston.
Wm. L. Richardson,	Boston.
Henry P. Walcott,	Cambridge.
John C. Warren,	Boston.
Henry W. Williams,	Boston.

CLASS III. — *Moral and Political Sciences.* — 61.

SECTION I. — 10.

Philosophy and Jurisprudence.

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Charles C. Everett,	Cambridge.
Horace Gray,	Boston.
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G. Stanley Hall,	Worcester.
Nathaniel Holmes,	Cambridge.
John E. Hudson,	Boston.
John Lowell,	Newton.
Josiah Royce,	Cambridge.
James B. Thayer,	Cambridge.

SECTION II. — 20.

Philology and Archæology.

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Lucien Carr,	Cambridge.
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SECTION III. — 18.

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Edward Atkinson,	Boston.
Edmund H. Bennett.	Boston.
Mellen Chamberlain.	Chelsea.
John Cummings.	Woburn.
Andrew M. Davis,	Cambridge.
Charles F. Dunbar,	Cambridge.
Samuel Eliot,	Boston.
A. C. Goodell, Jr.,	Salem.
Henry C. Lodge,	Nahant.
Augustus Lowell,	Boston.
Silas M. Macvane,	Cambridge.
John C. Ropes,	Boston.
Denman W. Ross.	Cambridge.
Charles C. Smith,	Boston.
F. W. Taussig,	Cambridge.
Francis A. Walker,	Boston.
Robert C. Winthrop.	Boston.

SECTION IV. — 13.

Literature and the Fine Arts.

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John Bartlett,	Cambridge.
George S. Boutwell,	Groton.
Martin Brimmer,	Boston.
J. Elliot Cabot,	Brookline.
Francis J. Child,	Cambridge.
Thos. W. Higginson,	Cambridge.
S. R. Koehler,	Boston.
Charles G. Loring,	Boston.
Percival Lowell,	Brookline.
Charles Eliot Norton,	Cambridge.
Horace E. Scudder,	Cambridge.
Barrett Wendell,	Boston.

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Class I. — *Mathematical and Physical Sciences.* — 36.

Section I. — 6.

Mathematics.

Fabian Franklin,	Baltimore.
Emory McClintock,	New York.
Simon Newcomb,	Washington.
H. A. Newton,	New Haven.
James E. Oliver,	Ithaca, N.Y.
J. N. Stockwell,	Cleveland, Ohio.

Section II. — 13.

Practical Astronomy and Geodesy.

Edward E. Barnard,	San José, Cal.
S. W. Burnham,	Chicago.
Geo. Davidson,	San Francisco.
Wm. H. Emory,	Washington.
Asaph Hall,	Washington.
George W. Hill,	Washington.
E. S. Holden,	San José, Cal.
James E. Keeler,	Allegany, Pa.
Sam. P. Langley,	Washington.
T. C. Mendenhall,	Washington.
William A. Rogers,	Waterville, Me.
George M. Searle,	Washington.
Chas. A. Young,	Princeton, N.J.

Section III. — 11.

Physics and Chemistry.

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Ira Remsen,	Baltimore.
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Section IV. — 6.

Technology and Engineering.

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Geology, Mineralogy, and Physics of the Globe.

Cleveland Abbe,	Washington.
George J. Brush,	New Haven.
Edward S. Dana,	New Haven.
James D. Dana,	New Haven.
Walter G. Davis,	Cordova, Arg.
Sir J. W. Dawson,	Montreal.
G. K. Gilbert,	Washington.
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Clarence King,	New York.
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J. Peter Lesley,	Philadelphia.
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Sam. L. Penfield,	New Haven.
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Alfred R. C. Selwyn,	Ottawa.
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SECTION II. — 4.

Botany.

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D. C. Eaton,	New Haven.
Wm. Trelease,	St Louis.
John D. Smith,	Baltimore.

SECTION III. — 8.

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Wm. K. Brooks,	Baltimore.
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O. C Marsh,	New Haven.
H. N. Martin,	Baltimore.
S. Weir Mitchell,	Philadelphia.
A. S. Packard,	Providence.
A. E. Verrill,	New Haven.

SECTION IV. — 5.

Medicine and Surgery.

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Jacob M. Da Costa,	Philadelphia.
W. A. Hammond,	New York.
Alfred Stillé,	Philadelphia.
H. C. Wood,	Philadelphia.

CLASS III. — *Moral and Political Sciences.* — 28.

SECTION I. — 7.

Philosophy and Jurisprudence.

T. M. Cooley,	Ann Arbor, Mich.
D. R. Goodwin,	Philadelphia.
A. G. Haygood,	Oxford, Ga.
James McCosh,	Princeton, N.J.
Charles S. Peirce,	New York.
Thos. R. Pynchon,	Hartford, Conn.
Jeremiah Smith,	Cambridge.

SECTION II. — 6.

Philology and Archæology.

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Timothy Dwight,	New Haven.
D. C. Gilman,	Baltimore.
A. C. Kendrick,	Rochester, N.Y.
E. E. Salisbury,	New Haven.
A. D. White,	Ithaca, N.Y.

SECTION III. — 9.

Political Economy and History.

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M. F. Force,	Cincinnati.
H. E. Von Holst,	Chicago
Henry C. Lea,	Philadelphia.
Edward J. Phelps,	Burlington, Vt.
W. G. Sumner,	New Haven.
J. H. Trumbull,	Hartford, Conn.
David A. Wells,	Norwich, Conn.

SECTION IV. — 6.

Literature and the Fine Arts.

James B. Angell,	Ann Arbor, Mich.
L. P. di Cesnola,	New York.
F. E. Church,	New York.
R. S. Greenough,	Florence.
William W. Story,	Rome.
Wm. R. Ware,	New York.

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(Number limited to seventy-five. Elected as vacancies occur.)

CLASS I.—*Mathematical and Physical Sciences.*—25.

SECTION I.—5.

Mathematics.

Francesco Brioschi,	Milan.
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Hugo Gyldén,	Stockholm.
Charles Hermite,	Paris.
J. J. Sylvester,	Oxford.

SECTION II.—6.

Practical Astronomy and Geodesy.

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H. A. E. A. Faye,	Paris.
William Huggins,	London.
Otto Struve,	Pulkowa.
H. C. Vogel,	Potsdam.

SECTION III.—11.

Physics and Chemistry.

Adolf Baeyer,	Munich.
Marcellin Berthelot,	Paris.
R. Bunsen,	Heidelberg.
H. L. F. Helmholtz,	Berlin.
August Kekulé,	Bonn.
Mendeleeff,	St. Petersburg.
Victor Meyer,	Heidelberg.
Lord Rayleigh,	Witham.
Sir H. E. Roscoe,	London.
Sir G. G. Stokes,	Cambridge.
Julius Thomsen,	Copenhagen.

SECTION IV.—3.

Technology and Engineering.

Lord Kelvin,	Glasgow.
F. M. de Lesseps,	Paris.
Maurice Lévy,	Paris.

CLASS II.—*Natural and Physiological Sciences.*—25.

SECTION I.—6.

Geology, Mineralogy, and Physics of the Globe.

H. Ernst Beyrich,	Berlin.
Alfred Des Cloizeaux,	Paris.
A. E. Nordenskiöld,	Stockholm.
C. F. Rammelsberg,	Berlin.
Henry C. Sorby,	Sheffield.
Heinrich Wild,	St. Petersburg.

SECTION II.—7.

Botany.

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E. Bornet,	Paris.
Sir Joseph D Hooker,	London.
Baron von Mueller,	Melbourne.
Julius Sachs,	Würzburg.
Marquis de Saporta,	Aix.
Eduard Strasburger,	Bonn.

Section III. — 9.

Zoölogy and Physiology.

Du Bois-Reymond,	Berlin.
Ludimar Hermann,	Königsberg.
Thomas H. Huxley,	London.
Albrecht Kölliker,	Würzburg.
Lacaze-Duthiers,	Paris.
Rudolph Leuckart,	Leipsic.
C. F. W. Ludwig,	Leipsic.
Louis Pasteur,	Paris.
J. J. S. Steenstrup,	Copenhagen.

Section IV. — 3.

Medicine and Surgery.

Sir Joseph Lister,	London.
Sir James Paget,	London.
Rudolph Virchow,	Berlin.

Class III. — *Moral and Political Sciences.* — 20.

Section I. — 2.

Philosophy and Jurisprudence.

James Martineau,	London.
Henry Sidgwick,	Cambridge.

Section II. — 7.

Philology and Archæology.

Ingram Bywater,	Oxford.
Sir John Evans,	Hemel Hempstead.
Pascual de Gayangos,	Madrid.
J. W. A. Kirchhoff,	Berlin.
G. C. C. Maspero,	Paris.
Max Müller,	Oxford.
Sir H. C. Rawlinson,	London.

Section III. — 8.

Political Economy and History.

Duc de Broglie,	Paris.
James Bryce,	Oxford.
Ernst Curtius,	Berlin.
W. E. Gladstone,	Hawarden.
Theodor Mommsen,	Berlin.
Sir J. R. Seeley,	Cambridge.
Jules Simon,	Paris.
Wm. Stubbs,	Oxford.

Section IV. — 3.

Literature and the Fine Arts.

Jean Léon Gérôme,	Paris.
John Ruskin,	Coniston.
Leslie Stephen,	London.

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  Moses Gerry Farmer, 401.
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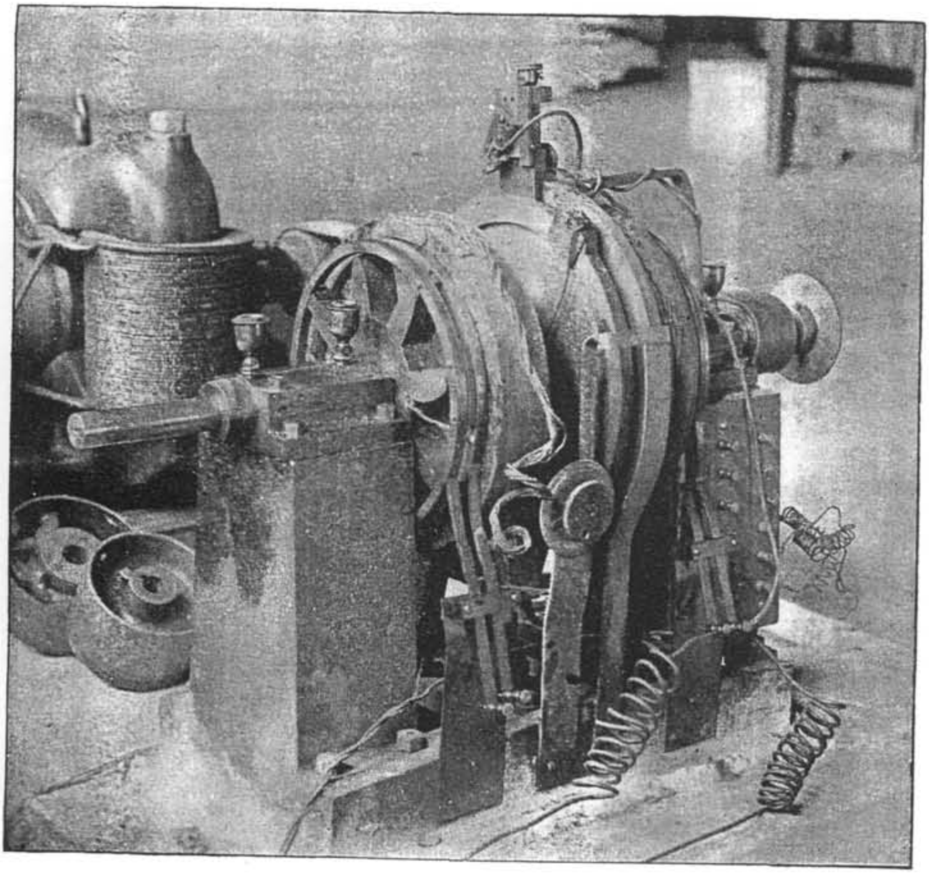


Fig. 1.

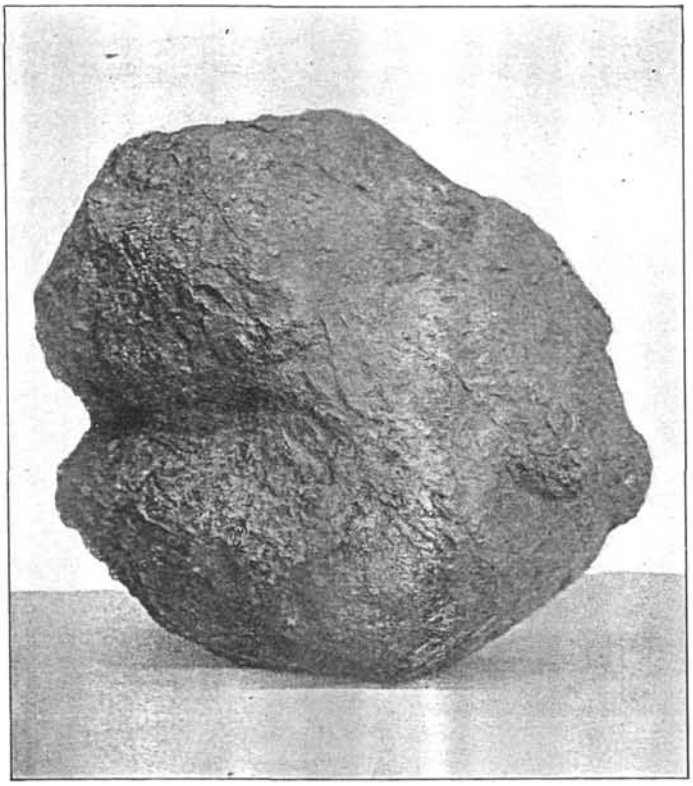


Fig. 1.
Largest Mass of the Smithville Iron.

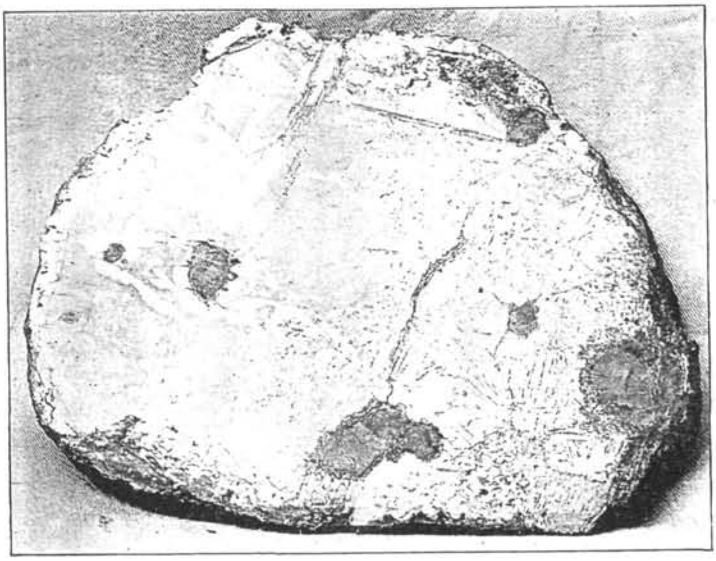


Fig. 2.
Largest Section of the Smithville Iron, Etched.
Shows at the right a nodule of graphite two inches in diameter.

PLATE I.

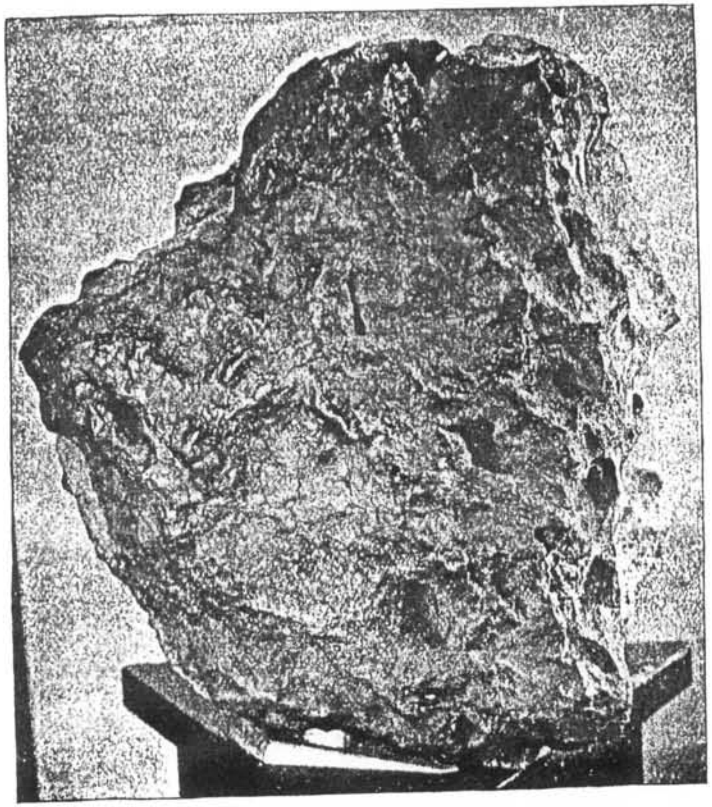


FIG. 1.—FRONT VIEW.

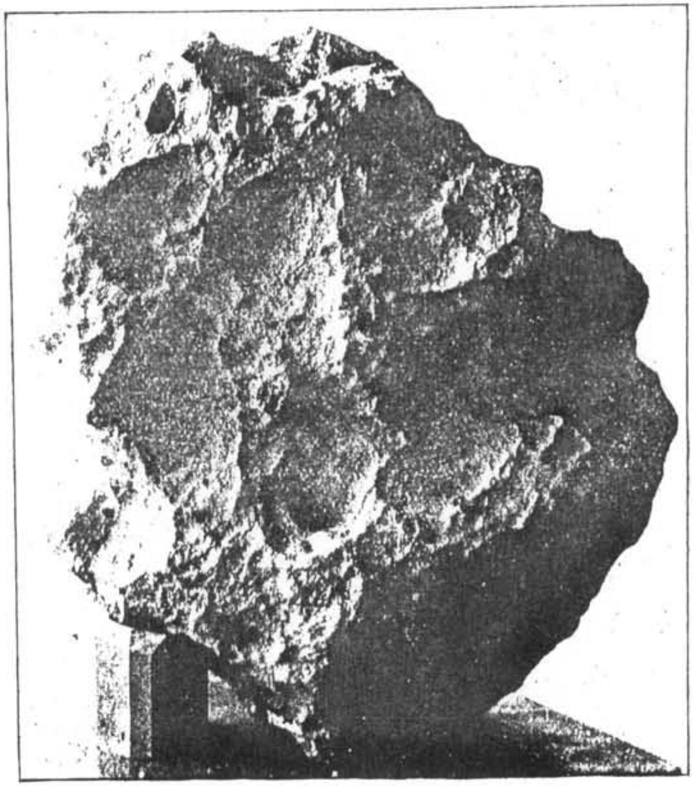
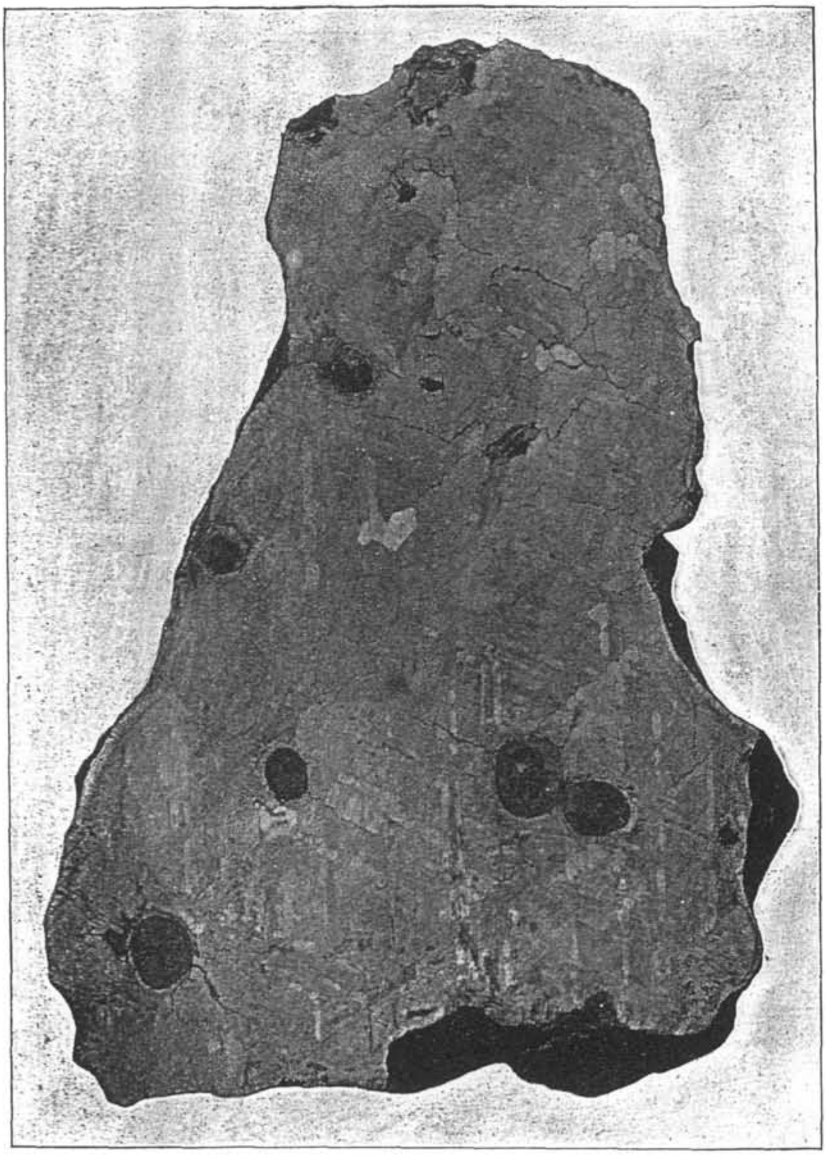


FIG. 2.—BACK VIEW.

Cañon Diablo Iron—Weight, 1087 pounds.

Actual Size. { Height, 25 inches.
Breadth, 23 "
Thickness, 15 "



Etched Slab of Cañon Diablo Iron.